In Synchrony with the Heavens

Studies in Astronomical Timekeeping and Instrumentation in Medieval Islamic Civilization

Volume Two • Instruments of Mass Calculation

DAVID A. KING

BRILL

IN SYNCHRONY WITH THE HEAVENS

VOLUME TWO

INSTRUMENTS OF MASS CALCULATION

ISLAMIC PHILOSOPHY
THEOLOGY AND SCIENCE

Texts and Studies

EDITED BY

H. DAIBER and D. PINGREE

VOLUME LV

IN SYNCHRONY WITH THE HEAVENS

Studies in Astronomical Timekeeping and Instrumentation
in Medieval Islamic Civilization

VOLUME TWO

INSTRUMENTS OF MASS CALCULATION

(STUDIES X-XVIII)

BY

DAVID A. KING

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To the memory of Ḥabash (Baghdad and Samarra), al-Khujandī (Rayy, also Baghdad),
Abū ʿAlī al-Marrākushī and Najm al-Dīn al-Miṣrī (Cairo),
Ibn al-Sarrāj (Aleppo), Ibn al-Shāṭir (Damascus),
and all the others, in gratitude for the privilege of an encounter
with their minds and with their handiwork.

Individual parts of this work are dedicated to the teachers and colleagues
who helped me to appreciate the achievements of these scholars
in their cultural contexts.

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Note: Vol. 1, entitled *The Call of the Muezzin* and containing Studies I-IX, was published by Brill Academic Publishers in 2004. This contains:

PREFACE

"He lives doubly who also enjoys the past."
Len Scammell (1924-1997).

We looked for instruments of mass calculation in Iraq and surrounding regions and we found a mountain of evidence proving that the astronomical instrumentation that concerns us here started right there in Iraq in the 8th and 9th centuries. From there, it spread to all corners of the Islamic world where serious astronomy was practiced. We can document a thousand years of Muslim activity in this field, none of which ever did anybody any harm.

In this book, I present materials for the history of astronomical instruments. It is well known that Greek astronomy was concerned with instruments for observation and for calculation, and that Europeans before the invention of the telescope were involved with the same kind of instruments. This missing chapter deals with instrumentation in the Islamic world during the period from the 9th to the 19th century. I wish I could have written a history of this activity, but I could not. If I had actually planned to publish this book, which I did not (see below), there are many topics that I would have wanted to include but that I have dealt with here only in passing. The reader will at least find extensive bibliographical references to treatments of such topics in other publications.

My purpose in this volume is not only to portray the richness and variety of Islamic instrumentation, but also to present some examples of European instruments previously considered to be European inventions but which we now know had Islamic precedents. It is well known to specialists that medieval European instrumentation was highly indebted to the Islamic tradition. What only recent research has shown is that, in addition, virtually all innovations in instrumentation in Europe up to *ca*. 1550 were either directly or indirectly Islamic in origin or had been conceived previously by some Muslim astronomer somewhere. (This does not, of course, exclude the possibility of independent development.) Thereafter European science and instrumentation took off in directions undreamed of in Antiquity and the Middle Ages, whereas in Islamic civilization a science that was essentially still medieval continued to be practiced and was generally deemed adequate for the needs of the society.[1]

Colleagues concerned with Renaissance European instruments generally have no conception of this: for example, if a trigonometric grid appears on a 16th-century English astrolabe, they attribute the innovative influence to Apian in early-16th-century Germany rather than to a tradition that started with al-Khwārizmī in 9th-century Baghdad, thence to al-Andalus, thence *via* Latin translations to medieval Europe. I do not expect my findings to have much effect on Euro-centric science history. Besides, numerous problems result from the fact that our understanding of the transmission of ideas relating to instrumentation and actual instruments is still extremely limited. But at least colleagues may now be encouraged to enquire whether

[1] On my use of the term "medieval" in the context of Islamic science see p. x to vol. 1.

this or that Renaissance innovation is indeed original. In many cases, we cannot rule out independent initiative anyway.

Recently some 12 volumes of reprints of early studies of Islamic instruments were published in Frankfurt, a monumental total of over 5,000 pages. So the subject is not new, but its scope has not been generally appreciated. Historians of mathematical astronomy have tended to scorn astronomical instruments, not least because they have not cared for those of their colleagues who were impassioned by instruments. Their loss! Historians of Islamic art may never discover that the largest single corpus of signed and dated metalwork comprises astronomical instruments. L. A. Mayer's valiant efforts to document astrolabists alongside other craftsmen (see below) have alas been wasted on our art-historian colleagues. In September, 2004, a conference entitled "Metals and Metalworking in Islamic Iran" was held at the Chester Beatty Library in Dublin. Scholars talked about pen-boxes and door-knockers and unfinished trays, but not about astrolabes. Since Iranian astrolabes are often more beautiful and more intricately worked than other metal objects, and not least because most of them are signed and dated, it is a disaster for the history of Islamic metalwork that they have suffered such neglect.

The study of Islamic instrumentation based on textual sources began in France in the 19th century and continued in Germany until in the early decades of the 20th. Major contributions included:

- ❖ Jean-Jacques Sédillot (*père*), *Traité des instruments astronomiques des Arabes composé au treizième siècle par Aboul Hhassan Ali de Maroc ...* , 2 vols., (Paris, 1834-1835), and Louis-Amélie Sédillot (*fils*), "Mémoire sur les instruments astronomiques des Arabes", (Paris, 1844), dealing with the monumental treatise on instrument construction and use by the late-13th-century scholar Abū ʿAlī al-Marrākushī.[1*]
- ❖ Joseph Frank, *Zur Geschichte des Astrolabs*, (Erlangen, 1920), on the history of non-standard astrolabes.
- ❖ Karl Schoy, *Gnomonik der Araber*, (Berlin & Leipzig, 1923), on sundial theory.[2]

The study of actual instruments began in earnest also in the 19th century, when various scholars published detailed descriptions of individual ones. Without wishing to ignore altogether various studies of the 17th and 18th centuries (now reprinted in Frankfurt—see above), mention should here be made of:

- ❖ Frédéric Sarrus, "Description d'un astrolabe construit à Maroc en l'an 1208" (Strasbourg, 1853).
- ❖ Franz Woepcke, "Über ein in der königlichen Bibliothek zu Berlin befindliches arabisches Astrolabium" (Berlin, 1855).
- ❖ Bernhard Dorn, "Drei in der Kaiserlichen Öffentlichen Bibliothek zu St. Petersburg befindliche astronomische Instrumente mit arabischen Inschriften" (St. Petersburg, 1865).
- ❖ William H. Morley, *Description of a Planispheric Astrolabe Constructed for Sháh Sultán Husain Safawí ...* (London, 1856).

[1*] On interest in Islamic science in Paris in the 19th century see Charette, *Orientalisme et histoire des sciences*.
[2] On Schoy and his work on Islamic science see Ruska, "Carl Schoy".

- ❖ *idem*, “Description of an Arabic Quadrant” (London, 1860).

Studies of this calibre in the 20th century were rare. I can think of only three:

- ❖ Josef Frank and Max Meyerhof, “Ein Astrolab aus dem indischen Mogulreiche” (Heidelberg, 1925).
- ❖ Ornella Marra, “Di due astrolabi ispano-moreschi conservati nel Museo di Capodimonte” (Naples, 1984).
- ❖ Gisela Helmecke, “Das Berliner Astrolab des Muḥammad Zamān al-Mašhadī” (Berlin, 1985).

Various attempts have been made, at different levels, to document the available sources. I mention:

- ❖ Robert T. Gunther, *The Astrolabes of the World* (Oxford, 1932).[3]
- ❖ Leon A. Mayer, *Islamic Astrolabists and Their Works* (Geneva, 1956).[4]
- ❖ Derek J. de Solla Price *et al*., *A Computerized Checklist of Astrolabes* (New Haven, Ct., 1973).[5]
- ❖ Emilie Savage-Smith, *Islamicate Celestial Globes—Their History, Construction, and Use* (Washington, D.C., 1985).
- ❖ Alain Brieux and Francis Maddison, *Répertoire des facteurs d'astrolabes et de leurs œuvres* (to be published by C.N.R.S. in Paris, but in December, 2004, still not ready for printing).

The study of Islamic instrumentation has progressed in leaps and bounds in recent years, not least as a result of the fact that several hundred Islamic instruments have been catalogued in Frankfurt for the first time (see below) and numerous examples of particular sophistication or historical importance have been studied in detail. The subject has also been dealt with for the first time as a chapter in the history of Islamic astronomy in general and of astronomical timekeeping in Islamic civilization in particular. Also, we now study Islamic instruments in the light of the associated textual tradition, drawing on the hundreds of treatises in Arabic (and also Persian and, to lesser extent, Turkish) dealing with instrumentation that were compiled during the millennium of Muslim preoccupation with the topic. My first contribution to the subject was a collection of early studies reprinted in

- ❖ *Islamic Astronomical Instruments* (London, 1987/1995).

Whatever their failings, these studies at least had the virtue of considering instruments in the light of relevant texts. An overview that I prepared in 1991 appeared only in translation, and the original has been elaborated here (see **X**). This was:

- ❖ “Strumentazione astronomica nel mondo medievale islamico” (Turin, 1991).

The potential of Islamic and medieval European instruments as historical sources is described in:

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[3] On the context of Gunther's work in Oxford see Simcock, ed., *Robert Gunther*.

[4] On the context of this remarkable work, one of a series in which Mayer also documented Islamic glassmakers (1955), architects (1956), woodcarvers (1958), metalworkers (1959), armourers (1962) and stonemasons (not published?), see *Mayer Memorial Volume*, pp. xi-xxvii, with an obituary and list of publications.

[5] For Price's publications on instruments see the list in the preamble to **XIIb**.

❖ "Astronomical Instruments between East and West" (Vienna, 1994).

This was appropriately addressed to colleagues in Islamic, Byzantine and Medieval Studies. The theme of our gathering was "*Realienkunde*" in the Middle Ages, one word for "the study of historical material objects" and something of an anathema to those many colleagues who believe that history is documented only in textual sources.

In another study, I presented two remarkable 17th-century Safavid instruments that had recently come to light:

❖ *World-Maps for Finding the Direction and Distance to Mecca—Innovation and Tradition in Islamic Science* (Leiden, 1999).

I attempted to show first that they did not fit into what we knew about contemporaneous instrumentation in Iran, second that they could only be understood in the light of earlier Islamic scientific achievements, and third that they bore not a trace of European influence. (On the early inspiration for the mathematics underlying the grids on these maps, see now **VIIc**. My claims about the Islamic inspiration behind certain European instruments, such the universal horary quadrant (*quadrans vetus*) and the universal horary dial (as on the *navicula de Venetiis*) are now documented more fully in **XIIa-b**.)

On three aspects of instruments, my investigations and descriptions are deficient. I refer first to two technological aspects of the objects: what they were made of, and how they were made. I never investigate the metallurgical composition of the instruments and seldom get involved with construction marks. Both topics are inadequately treated in the literature and alas no contribution to them is made here. Furthermore, I seldom get involved in detailed investigations of stellar positions indicated on instruments. For this we have a ground-breaking study:

❖ Burkhard Stautz, *Untersuchungen von mathematisch-astronomischen Darstellungen auf mittelalterlichen Instrumenten islamischer und europäischer Herkunft* (Bassum (D), 1997).

I occasionally refer to Stautz's findings. I have not developed the means to myself investigate graphically or numerically the star positions, as Stautz did using modern stellar data adjusted for the epoch of the instrument or its precursors or, where appropriate, medieval data from the manuscript sources. (Elly Dekker has criticized aspects of Stautz' methodology with regard to European astrolabes, and has published some more thorough investigations of a few instruments.)

There is a very real sense in which a supplement to the present volume has already been published. I refer to:

❖ François Charette, *Mathematical Instrumentation in Fourteenth-Century Egypt and Syria—The Illustrated Treatise of Najm al-Dīn al-Miṣrī* (Leiden, 2003).

This is a text edition with translation and detailed analysis of a 14th-century Egyptian treatise describing over a hundred instrument-types. Nothing like it has been published since Sédillot-*père* produced his monumental translation of one-half of the treatise of al-Marrākushī (see above). I have not incorporated most of Charette's findings regarding different kinds of Islamic instruments, which often go far beyond my own, so the reader of this volume would do well to have Charette's work at hand. On the other hand, I have included a few illustrations from the Chester Beatty manuscript to encourage readers to acquire Charette's book on this most remarkable discovery.

Likewise, two new studies by François Charette and Petra Schmidl take our knowledge of 9th-

century astronomy in Baghdad a major step forward. Both include editions of texts never studied previously, with translations and informed commentary. I refer to:

- "A Universal Plate for Timekeeping with the Stars by Ḥabash al-Ḥāsib: Text, Translation and Preliminary Commentary", *Suhayl* 2 (2001), pp. 107-159.
- "al-Khwārizmī and Practical Astronomy in Ninth-Century Baghdad. The Earliest Extant Corpus of Texts in Arabic on the Astrolabe and Other Portable Instruments", *SCIAMVS* 5 (2004), pp. 101-198.

There are many more such texts awaiting serious study.

I shall assume that the reader has at hand vol. 1 of this work, entitled *The Call of the Muezzin* (Leiden: E. J. Brill, 2004). In that I presented various studies (**I-IX**) dealing with timekeeping by the sun and stars and the regulation of the astronomically-defined times of Muslim prayer. In this volume, I begin with an overview of Islamic instrumentation, presenting detailed bibliographical about all previous studies (**X**). Then I present a rather curious history of an astronomical formula that was widely used in mathematical astronomy and astronomical instrumentation for over a thousand years, but which was previously virtually undocumented (**XI**). There follow two studies of universal horary quadrants and universal horary dials (**XIIa-b**). Studies of individual instruments of particular historical interest are included to show how much can extracted from them when they are examined closely (**XIII-XV**). Another study shows how much can be extracted from a group of instruments, this time, geographical information, either explicitly or implicitly featured on them (**XVI**). Another shows the potential of astronomical instruments to contribute to the history of Islamic art (**XVII**). Finally, I include an ordered list of early Islamic instruments to *ca*. 1500 (**XVIII**), in the hope that others will be inspired to turn their attention to these rich historical sources. (Many other instruments dating from after *ca*. 1500 have been omitted, simply because I do not control them.)

I actually never planned to publish this volume in this form. The studies now numbered **X-XII** were submitted to Brill in the Spring of 2003 along with **I-IX**, but it was found that the resulting book would be simply too large. It was decided to put **I-IX** in a first volume, already weighing 3 kg, and this was what was published under the title *The Call of the Muezzin*. This decision left **X-XII** for a rather small second volume. However, in the Spring of 2003, during the invasion and occupation of Iraq, I prepared a study (now **XIIIb**) of the oldest known astrolabe, formerly housed in the Archaeological Museum in Baghdad. To include **XIIIb** alone seemed unreasonable, so I rescued my descriptions (now **XIIIc**) of all early Eastern Islamic astrolabes from before *ca*. 1100, most of which were also made in Baghdad, from my unpublished catalogue of medieval Islamic and European instruments. Furthermore, during my sabbatical leave in the winter of 2003-04, and since various recent publications on astrolabes of particular historical importance were not easily accessible, I prepared **XIIId-e** and **XIV-XVIII** for inclusion as well. I rather wish that I could have spent my sabbatical enlarging **X** into a real overview of Islamic instrumentation, but I found concentration hard after listening every morning to the news from Iraq and elsewhere. I could have gone on rehashing old materials or plundering my unfinished instrument catalogue, but then, in Marrakesh in March, 2004, I was inspired by the words of my friend and travelling-companion Henry Spalding Schley III (*Pensées inédites*):

"To advance, sometimes one has to stop."

The reader must appreciate that these instruments are scattered in museums and private

collections all over the world, and the difficulties of conducting serious research on them will then be obvious. My research over the past couple of decades has been greatly facilitated by the generosity of certain major museums[6] and certain individual collectors. It is a pleasure to single out for special mention such splendid institutions as the Museum of the History of Science, Oxford; the Museo di Storia della Scienza, Florence; the National Museum of American History, Washington, D.C.; the Adler Planetarium, Chicago, Ill.; the National Maritime Museum, Greenwich; The British Museum, London; the Germanisches Nationalmuseum, Nuremberg; the Institut du Monde Arabe, Paris; the Museo Arqueológico Nacional, Madrid; and, last, but by no means least, three small but very important collections: the Benaki Museum, Athens; the Chester Beatty Library, Dublin, and the Davids Samling, Copenhagen.

Few museums have had the foresight to provide me with photographs free of charge. One that has is the Benaki Museum in Athens, and this I single out here for special mention and thanks. For the provision of photos I am grateful to all the institutions mentioned above and more besides, and especially to Jeremy Collins, formerly of Christie's, South Kensington, and Jacques van Damme of Brussels. A special word of thanks is due to Dominique Brieux for giving me all the photos left over from the project associated with the *Répertoire*.

The richest collections also merit my gratitude for unlimited access to their instruments: the Museum of the History of Science in Oxford, and the Museo di Storia della Scienza in Florence. Other museums, where I was only allowed to inspect one instrument at a time, or where I was forbidden to work on the instruments at all, are better not named here. However, where there is a will, there is a way, and some the illustrations presented here stem from such collections as these. Some subtle hints can be found between the lines of the main text, and a careful examination of the credits will reveal that photos from some of these uncooperative museums have come my way from the most surprising quarters. On the other hand, it should be mentioned that many museums are incapable of preparing decent photos of instruments. In the meantime, however, technological advances have made the acquisition of large quantities of photos something of an exercise in folly.

In the past few years my long-term project to prepare descriptions of all medieval Islamic and European instruments has progressed, and much that is new here is the result of the privilege of being able to inspect large numbers of instruments. That this project could get off the ground at all is due to the generosity of the German Research Foundation (Deutsche Forschungsgemeinschaft) in Bonn, which provided funding during 1992-96 (Islamic instruments) and 1998-2001 (European instruments). Much of the progress that was made in the early years was thanks to the participation of Kurt Maier (see the preamble to **XVIII**). It will still be a few years before any of this material gathered can be published, although a sample is included here (**XIIIc**), as well as a partial table of contents of the potential catalogue (**XVIII**). Certainly, besides the need for further funding, one of the greatest problems has been the acquisition of adequate photographs of instruments. During the course of my research, technology has advanced so rapidly that it has left me behind. I am left with hundreds of black and white photos, many of inferior quality, and have yet to request from a single museum that they prepare digitalized images of any instrument. The illustrations presented here are from "old-style" black and white photos. I had to purchase a scanner and a new computer

[6] These are listed here more or less in order of their importance for the study of Islamic instrumentation.

to make copies for Brill. For years I have been working with computers that were constantly on the blink.[7]

To my wife, Patricia, my appreciation for her companionship in many ventures over close to 35 years and her encouragement in this encounter with astronomical instruments, as well as her tolerance *vis-à-vis* yet another book that I had sort of promised I would not write.

I am very grateful to the Hessisches Ministerium für Wissenschaft und Kunst for sabbatical leave during the Winter Semester 2003-04. This enabled me to prepare this volume for publication in a very quiet place.

My debt to the various scholars to whom the various parts of this volume are dedicated will be obvious to all who know their works. I mention here, in addition, two friends and colleagues who have devoted their lives to the history of instrumentation, namely, Anthony J. Turner and Gerard L'E. Turner. It has been my pleasure and privilege to collaborate with both of them over many years, and to profit from their expertise.

My gratitude is also extended to all those members of my weekly instrument seminar in Frankfurt, with whom I have shared much of the material in this book at some stage or another: budding specialists in the history of Islamic science, Arabists and Islamicists, medievalists, general historians, archaeologists; high-school teachers of Mathematics or Physics; retired pharmacists, engineers, professors of Mathematics, and Lufthansa pilots; and even, on occasion, a few undergraduate students. All of them have contributed insights of one sort or another. Sven Ruhberg, in particular, has saved me on several occasions from blunders relating to technical matters. To Ryszard Dyga and Wolf-Dieter Wagner of the Frankfurt Institute and other *nudamāʾ* who cannot be named here, I extend my thanks for their willingness to get hold of materials and send them on to me in distant regions. Petra Schmidl valiantly corrected countless editions of the Arabic texts and achieved their final form. Wolf-Dieter Wagner kindly provided me with usable text from the originals of **XIIIe** and **XIVa**, most of which he had to retype. Once again, Brill has done me proud, thanks to the labours of Trudy Kamperveen, Tanja Cowall, and—last but by no means least—Ciska Palm of Palm Produkties.

As François Charette and several of my colleagues and students well know, the study of historical instruments is exciting but also contagious, and it is my hope that the present volume will generate further interest not only in Islamic instruments, but also in their medieval and Renaissance European counterparts. This volume is far from being the last word on Islamic instruments, and there is even more to be done on the European tradition.[8] In any case, I hope to have succeeded in demonstrating the importance of these splendid objects for furthering our understanding of both the history of astronomy and material culture in the Islamic world.

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[7] Several colleagues with a sense of humour have much appreciated my previous accounts of problems with computers. These are in my *Mecca-Centred World-Maps*, p. xxi, *The Ciphers of the Monks*, p. 19, and the Preface to vol. 1, pp. xii-xiii. This time around I have less to report than before, save that when I returned to Frankfurt in April, 2004, from my sabbatical in France, my Frankfurt iMac crashed altogether with the latest version of this book. It would not even open. My French Mac wizard, Patrick Alison, told me over the phone that every time I open the computer I should hold down four keys simultaneously: + option + P + R. (I wonder how many people on this planet know this!) I should continue using this procedure until my next visit to France in July, 2004, when he could repair it, and by which time the text should be with Brill.

[8] Anyone who would dispute this should look at the illustrations of Islamic instruments by Muṣṭafā Ṣidqī (see n. 13 to **V-10**), and the illustrations of European instruments by Georg Hartmann (see **XIIb-10**). Neither the Cairo and Weimar manuscripts in which these occur have been published. The present volume, together with the first volume, contains just a few of these illustrations.

STATEMENT ON PREVIOUS PUBLICATION OF PARTS OF THIS VOLUME

Parts of this work have been published previously. They are included here because they are all essential to the overall picture provided by the ensemble of studies. They have been revised and brought into line with the other studies; in particular, the references and bibliography have been updated.

General remarks:
Parts XI, **XIIa-b**, **XIIIa-c**, **XIVd-g**, **XVII** and **XVIII** have not been published previously in any form resembling their present one.
Parts X and **XIVb** are here published in English for the first time.

Remarks to specific sections of the second volume:

- An Italian translation of an earlier version of **Part X** was published as "Strumentazione astronomica nel mondo medievale islamico", in *Gli strumenti*, Gerard L'E. Turner, ed., Turin: Giulio Einaudi, 1991, pp. 154-189 and 581-585. The text has been considerably expanded here.
- **Part XI** has not been published previously.
- The section of **Part XIIa** dealing with the Baghdad treatise has appeared separately as "A *Vetustissimus* Arabic Treatise on the *Quadrans Vetus*", in *Journal for the History of Astronomy* 33 (2002), pp. 237-255.
- A summary of some sections of **Part XIIb** entitled "14th-Century England or 9th-Century Baghdad? New Insights on the Origins of the Elusive Astronomical Instrument Called *Navicula de Venetiis*" was published in *Astronomy and Astrology from the Babylonians to Kepler—Essays Presented to Bernard R. Goldstein on the Occasion of his 65th Birthday*, Peter Barker, Alan C. Bowen, José Chabás, Gad Freudenthal and Tzvi Langermann, eds., special issues of *Centaurus* 45 (2003) and 46 (2004), I, pp. 204-226.
- **Part XIIIa** has been substantially modified from the materials in "The Neglected Astrolabe", in *Mathematische Probleme in Mittelalter—Der lateinische und arabische Sprachbereich*, Menso Folkerts, ed., Wiesbaden: Harrassowitz, 1996, pp. 45-55 (Islamic), and *The Ciphers of the Monks—A Forgotten Number Notation of the Middle Ages*, Stuttgart: Franz Steiner, 2001, pp. 359-379 (European).
- **Part XIIIb** has not been published before.
- Most of **Part XIIIc** is taken from my unpublished catalogue of medieval Islamic and European instruments. The descriptions of the Kuwait astrolabes of Nasṭūlus and al-Khujandī, taken from the same source, were published in "Early Islamic Astronomical Instruments in Kuwaiti Collections", in Arlene Fullerton & Géza Fehérvári, eds., *Kuwait: Art and Architecture—Collection of Essays*, Kuwait (no publisher stated), 1995, pp. 76-96.

- A modified version of **Part XIIId** was published as "A Remarkable Italian Astrolabe from *ca*. 1300—Witness to an Ingenious Tradition of Non-Standard Astrolabes", in *MUSA MUSAEI: Studies on Scientific Instruments and Collections in Honour of Mara Miniati*, Marco Beretta, Paolo Galluzzi and Carlo Triarico, eds., Florence: Leo S. Olschki, 2003, pp. 29-52.
- **Part XIIIe** is modified from "The Origin of the Astrolabe according to the Medieval Islamic Sources", *Journal of the History of Arabic Science* (Aleppo) 5 (1981), pp. 43-83, repr. in *Islamic Astronomical Instruments*, London: Variorum, 1987, repr. Aldershot: Variorum, 1995, III.
- **Part XIVa** is modified from "The Medieval Yemeni Astrolabe in the Metropolitan Museum of Art in New York", *Zeitschrift für Geschichte der arabisch-islamischen Wissenschaften* (Frankfurt) 2 (1985), pp. 99-122, and 4 (1987/88), pp. 268-269 (corrections). Appendix A is new, and Appendix B is modified from a review in *Yemeni Update* 44 (2002), available on the Internet at www.aiys.org/webdate/afdking.html.
- A French version of **Part XIVb** was part of my contribution "L'astronomie en Syrie à l'époque islamique", to the exhibition catalogue *Syrie—mémoire et civilisation*, Sophie Cluzan, Éric Delpont and Jeanne Mouliérac, eds., Paris: Flammarion (Institut du Monde Arabe), 1993, pp. 386-395 and 432-443. The description of the astrolabic plate of al-Wadāʿī appeared already in my *Islamic Astronomical Instruments*, London: Variorum, 1987, repr. Aldershot: Variorum, 1995, VIII. The description of the Damascus ceramic qibla-bowl is taken from my *World-Maps for Finding the Direction and Distance to Mecca: Innovation and Tradition in Islamic Science*, Leiden: E. J. Brill, and London: Al-Furqan Islamic Heritage Foundation, 1999, pp. 110-114, 168-170, and 478-480. The descriptions of various other instruments are taken from my (incomplete and unpublished) catalogue of Islamic instruments to *ca*. 1500.
- **Part XIVc** is adapted from "The Monumental Syrian Astrolabe in the Maritime Museum, Istanbul", in *Aydın Sayılı Özel Sayısı*, I-III, a special issue of *Erdem* (Ankara: Atatürk Kültür Merkezi), in three parts (9:25-27), Ankara: Türk Tarih Kurumu Basımevi, 1996-1997, II, pp. 729-735 and 10 pls.
- **Part XIVd** has not been published previously.
- **Part XIVe** is modified from a version submitted to a *Festschrift* for Professor Ekmeleddin İhsanoğlu, Istanbul, currently in press.
- **Part XIVf** has not been published previously.
- **Part XIVg** is based on my descriptions prepared for Christie's of London (*Christie's London 04.10.1995 Catalogue*, pp. 20-21, lot 61 (rete), and *Christie's London 05.04.2001 Catalogue*, pp. 43-45, lot 32 (mater)).
- **Part XV** was first published as "An Astrolabe from 14th-Century Christian Spain with Inscriptions in Latin, Hebrew and Arabic—A Unique Testimonial to an Intercultural Encounter", *Suhayl—Journal for the History of the Exact and Natural Sciences in Islamic Civilisation* (Barcelona) 3 (2002/03), pp. 9-156.
- **Part XVI** was first published as "Bringing Astronomical Instruments back to Earth—The Geographical Data on Medieval Astrolabes to *ca*. 1100", in *Between Demonstration*

and Imagination: Essays in the History of Science and Philosophy Presented to John D. North, Arjo Vanderjagt and Lodi Nauta, eds., Leiden: E. J. Brill, 1999, pp. 3-53. [This new version omits two significant errors in the original, identified in the preamble.]

- ❖ **Part XVII** is considerably expanded from the appendix “The Quatrefoil on Medieval Astrolabe Retes” to *The Ciphers of the Monks—A Forgotten Number Notation of the Middle Ages*, Stuttgart: Franz Steiner, 2001, pp. 380-390.
- ❖ **Part XVIII** has not been published previously, and has been fixed up from the raw version available at: www.uni-frankfurt.de/fb13/ign/instrument-catalogue.html.

Some of the studies in their original manifestations suffered in ways that colleagues should read about, so that they can plan ahead when submitting papers to editors and/or publishers.[1]

[1] In one case, the editors requested bibliographical citations in the footnotes and then themselves extracted the bibliographical information from the footnotes to include in a separate bibliography, without much thought for the order of the entries. In another, a separate bibliography was provided by this author, as required by the format of the journal in question, but the editors changed their minds, and themselves inserted the bibliographical information into the footnotes, without any feeling for the rather sensitive nature of the abbreviations used, and introducing new (and often absurd) abbreviations for second citations. My favourite was “The Earliest European”. In yet another study, the editors removed the star-names from the text and put them in footnotes. Publishers are very careless about returning illustrations, and one usually has to demand their return. In one case, I realized that I was missing a complete set of photos only when I needed them for this volume. Fortunately, I still had the negatives. One should never let editors or publishers decide what is important: one team made the illustration of an astrolabe “horse” larger than the illustration of the back of the astrolabe itself.

I have had worse problems with other articles not presented here. My favourites were:

(1) A bibliographical essay on the history of sundials in which I referred to numerous sources in the text by abbreviations identified in the bibliography: an over-zealous editor removed the abbreviations, but only from the bibliography, rendering havoc to the order. The printers were persuaded to reprint the text from my original version.

(2) An essay on instruments in some conference proceedings (UCLA, Los Angeles, 1999) in which the printer rendered half of each of the long vowels as a *different* long vowel. How he achieved this confusion is beyond me. In any case, every one of the many long vowels in the text had to be controlled and changed by hand. The article was already out-of-date when it was published in 2004.

(3) An essay on Islamic astronomy in other conference proceedings (TU, Berlin, 1998) for which the editors sat on the text for years, and then demanded that I prepare immediately a German version because the proceedings would be published both in Germany and the US. This offer, made in the middle of a sabbatical, was refused.

(4) Last, and worst, was the article on “Science in the Service of Islam” that I was invited to submit to UNESCO’s scientific journal *impact of science on society* in 1991, and which was to have appeared in various languages. First, citing reasons of space, the editors removed all of the direct quotes from the *Qurʾān* and the (Sunnī and Shīʿī) *ḥadīth*. This enabled the person who was entrusted with the preparation of an Arabic translation to add a series of footnotes to the effect that “the author does not seem to know that in the *Qurʾān* ... ... ”. The translator further did not recognize one *ḥadīth* I had cited, which happened to be a Shīʿī *ḥadīth* (and had been clearly identified as such in my original paper), and he consequently accused *me* of fabricating it! He also converted all dates in my text as though they were Hijra dates, so that Cairo became founded in 969 H or 1561. The disastrous Arabic translation was fortunately withdrawn and never published. For these reasons, the first account of “Science in the Service of Islam” appeared in English, French, Portuguese, Chinese and Korean, and since then also in German, Italian and Persian, but not in Arabic.

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Notes: The reader will find here the main modern sources for the history of Islamic astronomy and astronomical instrumentation, including conference proceedings and exhibition catalogues. Many studies have been reprinted in various collected volumes, notably those published by Variorum; those individual studies related to astronomical timekeeping and related aspects of mathematical astronomy that are particularly relevant to this study are also listed here. The abbreviations introduced below are used throughout this book. Earlier publications of mine that are reprinted in these two volumes are indicated by diamonds.

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Part X

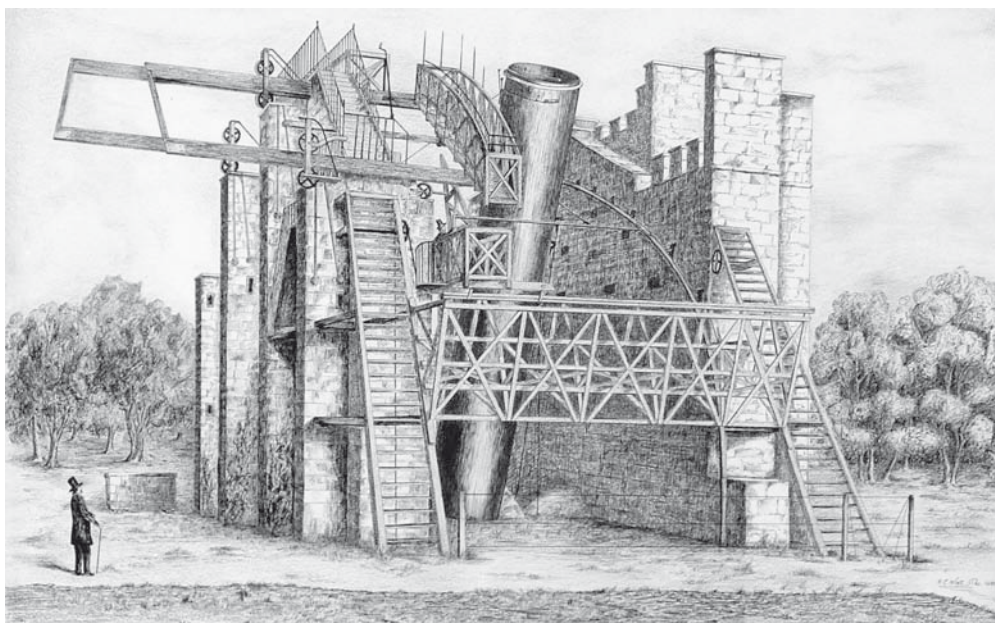
Astronomical instrumentation in the medieval Islamic world

To my father,
Henry C. King

DEDICATION,
ACKNOWLEDGEMENTS AND NOTES TO THIS VERSION

This study is dedicated to my father, Henry C. King, on the occasion of his 90th birthday, March 9th, 2005. When he was thirteen years old, his father gave him a copy of Hutchinson's *Splendour of the Heavens*, a newly-published large and serious volume on popular astronomy. This spelled eventual doom for my grandfather's baking business, since it marked the beginning of my father's life-long interest in astronomy. With a gargantuan effort that was remarkable even in those days, he earned the BSc, MSc and PhD degrees by participating in correspondence courses at the University of London, writing his doctoral thesis under the extremely difficult conditions of the time. His first career was in ophthalmic optics, but then in the 1950s he turned to planetaria, directing first the one in London, then the one in Toronto.

At age 13 he sketched a young lad pointing a telescope towards the moon, and at age 18 he drew the splendid 6-foot reflecting telescope erected by the Earl of Rosse at Parsonstown in Ireland (see **Figs. 1-2**).

Fig. 1: Rarely can a teenager's fancy develop into a life-long passion.
Fig. 2: The walls of the "Leviathan of Parsonstown", erected during 1842-44, are some 20 metres high, and attempts to use it for meridian observations under an Irish sky were not very successful (see Henry King, *The History of the Telescope*, pp. 210-216). I include this picture here not least to point out that the early-15th-century meridian sextant of Ulugh Beg (see **Fig. X-2.1**) was 40 metres in radius, and that also Muslim scholars had problems with unduly large instruments. [Photo courtesy of Günter Gloth.]

This passionate interest in telescopes, and later, also astronomical clocks, was to manifest itself in two monumental works, each the first on their subject:

- ❖ *The History of the Telescope*, London & New York: Charles Griffin, 1955, repr. New York: Dover Publications, Inc., 1979. This was developed from his doctoral thesis.
- ❖ *Geared to the Stars—The Evolution of Planetariums, Orreries, and Astronomical Clocks* (in collaboration with John R. Milburn), Toronto, Buffalo, N.Y. & London.: University of Toronto Press, 1978.

My father was also inspired to write numerous more general publications, of which I mention just two:

- ❖ *The Background to Astronomy*, London: C. Watts, 1956, repr. New York: G. Braziller, 1958.
- ❖ *Exploration the Universe: The Story of Astronomy (from the Astrolabe to the Radio Telescope)*, London: Secker & Warburg, 1964. [Words in brackets only on the dust-jacket.]

But his interests also lay elsewhere, and in the 1980s he prepared two book-length monographs that never appeared in print because, upon his retirement to England, he found no interested publishers:

- ❖ *Last Things. Ideas of End-Events, Natural and Divine*, a cross-cultural approach to death and resurrection; and
- ❖ *Aspects of Time*, a cultural history of Western attempts to deal with the notion of time.

One of the chapters of my father's *Background to Astronomy* (1956) is entitled "Muslim Torchbearers". It is an honest attempt to bridge the gap between classical astronomy and medieval and Renaissance European astronomy, which, I suspect, most general historians of astronomy would still regard as adequate. Years ago, when he was visiting us in Cairo, my father said to me that if one had a clock, one would not need any of the numerous tables that I had found in the Egyptian National Library and elsewhere, and which I eventually described in the first volume of this work. To this, at the time, I could only respond that if one had the tables and an astrolabe, one would not need a clock. He would also favour a clock over an astrolabe or any of the other instruments I describe here in this volume. But without my father, there would be neither of these volumes, and no contribution from me in *Astronomy before the Telescope* (London, 1996). For this and for much more, I am profoundly grateful.

The first version of this paper was developed from some preliminary remarks published as "Astronomical Instrumentation in the Medieval Near East", in my *Islamic Astronomical Instruments*, London: Variorum, 1987, I. It was published as "Strumentazione astronomica nel mondo medievale islamico", in the richly illustrated volume Gerard L'E. Turner, ed., *Gli strumenti*, Turin: Giulio Einaudi, 1991, pp. 154-189 and 581-585. A summary in English appeared as "Some Remarks on Islamic Astronomical Instruments", *Scientiarum Historia* (Brussels) 18:1 (1992), pp. 5-23.

In this new version I have inserted references to various instruments that have come to light in the past ten years and have updated the bibliography. There are still insufficient references to Charette, *Mamluk Instrumentation*, which is an indispensable companion to this essay. Inevitably, some of the material on astrolabes and quadrants is duplicated in **XIIIa**. I have changed

the illustrations in the first version, moving some, especially Abbasid and Mamluk instruments, to other parts of this book (see now **XIIIb-c** and **XIVb**). I have resisted the temptation to include more than a few references to medieval and Renaissance European instruments that were highly indebted to the Islamic tradition. Eventually, perhaps, this essay should be expanded into a separate book into which these influences are clearly described.

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CHAPTER 1

INTRODUCTORY REMARKS

> "Instruments are the preferred icons of science. In the history of Eastern and Western art, astronomical instruments almost invariably accompany representations of astronomers and astrologers, who may be portrayed holding an astrolabe, standing next to a globe or an armillary sphere, or performing an altitude measurement through the sights of parallactic rulers or an horary quadrant. In Islamic art and literature, the astrolabe had a pre-eminent status, as it symbolized and embodied the science of astronomy and, perhaps even more, astrology. ... ." François Charette, *Mamluk Instrumentation* (2003), p. 3.

> "It is a pity that so many modern historians and philosophers of modern science seem to be "born-again" theoreticians. They miss that sense of the craft of experimental science that would have come to them from experience at the bench. Too often they suppose that science is a department of intellectual history and that the only role of experimentation is to confirm (or, with Popper, to falsify) a succession of theories. Worse still, the devices used for this testing are awarded even less significance and are assumed to have evolved over the centuries from simple instruments of measure." Derek de Solla Price, "Instruments of Reason" (1981), p. 15.

> "Text-based outlines can foster distortions ... ." Valerie Flint, "Astrology in the Middle Ages" (1990), p. 23.

Our knowledge of astronomical instrumentation in the Islamic world between the 8th and 19th centuries is derived essentially from two main sources:
(1) the instruments which survive in various museums and private collections around the world, and
(2) the treatises on the construction and use of instruments which are preserved in manuscript form in libraries mainly in Europe and the Near East.

The surviving Islamic instruments are legion, over 600 astrolabes, over 150 celestial globes, and a few dozen each of quadrants and sundials, although most postdate the creative period of Islamic science that lasted from the 8th to the 15th century. To understand these instruments one has to learn their language: only a minority of the scholars who have written on instruments know this language. It is not difficult to identify this small subgroup: they are invariably authors of detailed descriptions of instruments. (The others can be safely classified as those who have never actually published an instrument.) A few of these instruments survive only in European examples. The texts exist in similar profusion, and not a few of these were compiled during the early period of Islamic science. Again, without the necessary languages there is no access to these primary sources, unless they have fortuitously been translated into a language one can read. Some texts describe instruments far more interesting than the standard astrolabe or quadrant or sundial, and of which there are no surviving examples. Many more manuscripts have yet to be uncovered in the various uncatalogued collections of Arabic, and also Persian and Turkish, scientific manuscripts, particularly those in libraries in the Near East and India.

Also some texts in Latin and/or medieval European vernaculars describe what are essentially Islamic instruments in European guise.

To understand the function of some of these instruments it is necessary to grasp only a few basic astronomical notions: for more details than those presented here see **I-1.1-2**. It is convenient to consider the heavens fixed as on a sphere about the observer. The celestial sphere appears to rotate about a celestial axis once in a day-and-night. The altitude of the (northern) celestial pole above the horizon is the same as the latitude of the locality on the terrestrial sphere. The meridian is the great-circle passing through the celestial pole and the zenith, the point directly above the observer; the meridian defines the north and south points on the local horizon. The celestial equator is the great-circle perpendicular to the celestial axis, and it passes through the east and west points of the horizon. Celestial bodies appear to traverse the sky on small-circles parallel to the celestial equator. The great-circle perpendicular to the meridian and passing through the east and west points is called the prime vertical. The altitude of any celestial body above the horizon and its direction around the horizon, called azimuth, can be measured directly.

The sun appears to move against the background of the fixed stars during the course of a year: its path, called the ecliptic, is inclined to the celestial equator at an angle of about $23^1/_2$°, called the obliquity. This angle decreases perceptibly over the centuries. The moon and planets appear to move along the ecliptic (in the direction opposite to that of the apparent daily rotation of the celestial sphere) but they, unlike the sun, also wander from side to side of it. To find the positions of the sun on the ecliptic or of the moon and planets with respect to it, the ancients developed mathematical models, either arithmetical or geometrical. The so-called fixed stars also move parallel to the ecliptic perceptibly over the centuries with a motion known as precession. It was necessary to determine their positions for a specific epoch and update star catalogues from time to time. Celestial coordinates were measured either with respect to the ecliptic (longitude and latitude) or with respect to the celestial equator (right ascension and declination).

Knowing the position of the celestial body in a celestial coordinate system and being able to measure its position relative to the horizon enables one to determine the time, in fractional units of the day-and-night interval, defined either as 24 hours or 360°. In Antiquity and in the Islamic Middle Ages, time was also measured in seasonal hours, twelfth divisions of the length of day or night; these seasonal hours have the disadvantage that they vary from one latitude to another and change in length throughout the year. Also one can determine the instantaneous position of the ecliptic relative to the horizon, thought to have been of influence on the affairs of men.

It is convenient to distinguish between two main categories of Islamic instruments, namely, observational and non-observational instruments. Those instruments used by Muslim astronomers for observations followed closely in the tradition of the devices described by Ptolemy of Alexandria (*fl*. *ca*. 140 A.D.): the armillary sphere, a physical representation of specific astronomically-significant circles on the celestial sphere, such as the horizon, the meridian, the celestial equator and the ecliptic; the mural quadrant, for measuring the meridian altitudes of celestial bodies; and the parallactic ruler, for measuring the zenith distance of a celestial body.

Instruments whose primary function was not observational are mainly for solving problems of spherical astronomy, the mathematics of configurations on the celestial sphere about the observer. The main problems are related to timekeeping, using the risings and settings of the sun and stars over the local horizon, or more commonly, the culminations of the sun and stars across the local meridian. Such instruments include:

(1) the celestial sphere—a model of the universe in which the sun and stars are represented on a sphere that can rotate about the celestial axis, so that risings and settings can be simulated over any horizon;

(2) the "analogue computer" known as the astrolabe for representing—in two dimensions rather than three—the positions of the sun and the fixed stars with respect to the local horizon;

(3) mathematical grids like the trigonometric quadrant for obtaining numerical solutions to problems of trigonometry without calculation, and

(4) sundials and other devices for measuring the time of day by means of shadows.

Another variety of Islamic instrument was:

(5) the equatorium, a device for determining planetary positions according to geometric models of the Ptolemaic kind for the sun, moon, and planets.

With the exception of the trigonometric grids and numerous instruments in the form of quadrants, these instruments were known to the Muslims from Greek sources. However, what the Muslim astronomers did with them constitutes a colourful chapter in the history of astronomy. For some examples, see **Figs. 1.1-8**, inserted here for technical reasons. (The explanations are sometimes very complicated and may not be digestible until the reader has worked through the rest of this study.)

Treatises on the construction and use of various instruments abound, but only a few have been published. The two major Islamic treatises on instrumentation were:

(1) The *Kitāb al-Mabādiʾ wa-'l-ghāyāt fī ʿilm al-mīqāt*, meaning something like "An A to Z on astronomical timekeeping", by the Maghribi astronomer Abū ʿAlī al-Marrākushī (Cairo, *ca*. 1280), dealing with all of the standard instruments of his day, and including a detailed survey of spherical astronomy with numerous tables, as well as a series of texts culled from earlier sources on the use of different instruments. This treatise was investigated by the Sédillots *père et fils* in Paris in the mid 19th century and again by Carl Schoy in the early decades of the 20th century.

(2) An anonymous untitled treatise that can be attributed to Najm al-Dīn al-Miṣrī (Cairo, *ca*. 1325), in which he describes and illustrates over 100 types of instruments known to him, some invented by himself. This treatise, discovered only 20 years ago, is full of surprises, and François Charette has recently published a model edition with translation and commentary.

See below on other works of consequence on instrumentation by such personalities as Ḥabash al-Ḥāsib (Baghdad, 9th century) and Abū Jaʿfar al-Khāzin (Baghdad, 10th century).

No detailed overview of Muslim achievements in astronomical instrumentation exists. From the 19th century we have several detailed and highly competent descriptions of individual instruments, which alas had few counterparts in the 20th century. These early writings are now

Fig. 1.1: An artist's view of the astronomers and their instruments at the Istanbul Observatory in the late 16th century. The director, Taqi 'l-Dīn, is depicted holding a standard astrolabe, and most of the other instruments are well known. However, many far more interesting instruments are described in Arabic manuscripts, such as those stacked horizontally on the upper right. These manuscripts are now in the University Library in Leiden. [From MS Istanbul UL Yıldız 1404, courtesy of Istanbul University Library.]

Fig. 1.2: In this miniature from a 15th-century copy of the five epic poems known as *Khamsa* or *Panj ganj*, "Five Treasures", of the celebrated 12th-century poet and thinker Ḥakīm Niẓāmī Ganjawī, an astrologer is determining the time of day to see whether the hour is propitious for Iskandar (Alexander), appropriately shown on an elephant, to engage in battle. The astrologer would have needed more than an astrolabe to make an appropriate pronouncement, unless he had a whole corpus of astrological lore in his head. But astrologers also had their own futures in mind. The prediction of Taqi 'l-Dīn made in Istanbul in 1577 on the basis of the appearance of a comet, namely, that the Ottomans would be victorious over the Safavids, turned out to be wrong, and, as a direct consequence, the observatory so carefully erected by the astronomer—see **Fig. 1.1**—was razed to the ground. Here, as in the miniature of the observatory, the astrolabe is symbolic of the astronomer-astrologer's profession. It was beyond the artist to depict more than a blank plate (*ṣafīḥa*), albeit appropriately held with a cord attached to the throne. [From MS Istanbul TIEM 1939, courtesy of the Türk ve İslâm Eserleri Müzesi. On Niẓāmī Ganjawī see the splendid article in EI_2 by Peter Chelkowski. On the context see also Saliba, "The Astrologer in Islamic Society".]

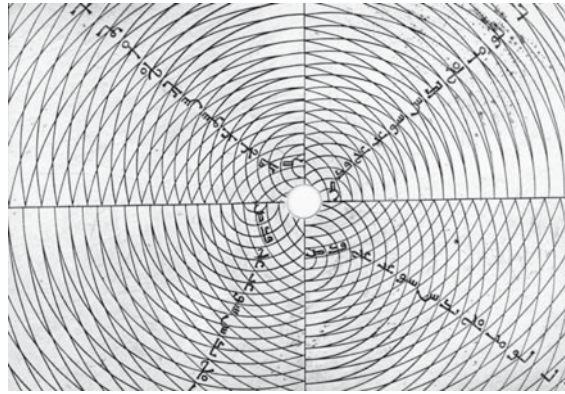



Fig. 1.3: Islamic instrumentation reached remarkable levels of sophistication, which is best appreciated from the instruments of al-Wāsiṭī and al-Khujandī in the 10th century and Ibn al-Sarrāj and Ibn al-Shāṭir in the 14th. Here, a detail of the markings on one of the plates in the magnificent astrolabe of Ibn al-Sarrāj (#140). Four latitudes are represented on each plate, and the astrolabic markings have been folded over so that each set fits in a quadrant. It took some years to figure out how some of the highly complicated markings on this instrument were to be used. [Courtesy of the Benaki Museum, Athens.]

Fig. 1.5: Another astrolabe with decorative rete made by Muḥammad ibn Ḥāmid al-Iṣfahānī in the late 12th century (#1211). This is not yet published, but at least the art historical aspects of the rete have been studied: see Müller-Wiener, "Das Astrolab des Muhammad b. Hâmid al-Isfahânî". [Courtesy of the Archaeological Museum, Tehran.]

←
Fig. 1.4: The Muslims transformed astronomical instruments into scientific works of art. Here, the spectacular London astrolabe with a zoomorphic rete made by ʿAbd al-Karīm al-Miṣrī in Damascus in the early 13th century (#104). This is the sole surviving complete astrolabe by this maker; a solitary rete survives in Oxford (#103). Both of these pieces, already known to Gunther, merit a detailed new study, but researchers will fight shy because the signature and date on the first instrument have been tampered with, and the second instrument is incomplete. [From Gunther, *Astrolabes*, I, pl. LV, opp. p. 236; object in the British Museum.]

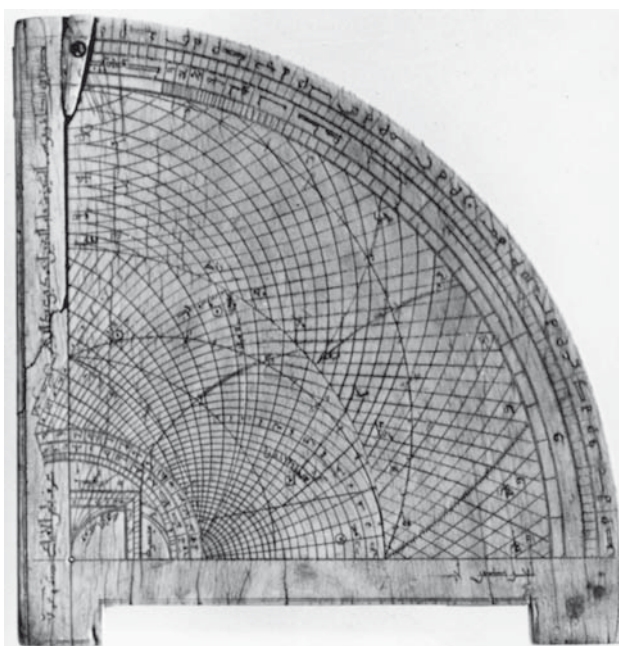



Fig. 1.6: This splendid ivory quadrant was made in Cairo or Damascus in 741 H [= 1340/41] by Taqi ʿl-Dīn Abū Ṭāhir (#5009), otherwise known to us as the author of some treatises on a universal quadrant (*Cairo ENL Survey*, no. C56). It bears astrolabic markings for two different latitudes. The inner markings are standard, with a pair of arcs representing the ecliptic, and are for latitude 30°, serving Cairo. The outer ones are folded over, with a single arc for the entire ecliptic, and they are for latitude 33°, serving Damascus. (The latter markings are called *musattar*: see Charette, *Mamluk Instrumentation*, pp. 86-87.) It is not known in which of these cities the maker was active. Within these markings is a traditional (since the 9th century) combination of a universal horary quadrant and shadow square. The other side bears a sexagesimal trigonometric grid: see **Fig. 6.1.3**. The instrument well reflects the ingenuity of the astronomers of Egypt and Syria during the Mamluk period, especially in the late 13th and 14th century. Astronomers in Europe at that time would not have known what to make of this piece, let alone how to use it. There is another quadrant by Abū Ṭāhir (#5010), this time in wood, in the Chester Beatty Library, Dublin; it is alas very discoloured and difficult to reproduce: see **Figs. V-9.3** and **XI-8.2e**. After working on Mamluk instruments and instrument texts for 30 years, I still do not know what to make it or how it works. [Courtesy of the Benaki Museum, Athens.]

Fig. 1.7: This instrument well illustrates the dilemma of Islamic science and its ultimate fate. It is an Ottoman qibla indicator from *ca*. 1800 with a magnetic compass attached (#8022) and it is signed by one Muḥammad ʿIzz al-Ṣabbāgh. One should align the instrument with its diameter true east-west and then turn the pointer to the appropriate qibla. For the latter purpose, some 36 divisions of the world around Mecca are identified in the diagram underneath the compass, defined according to the Islamic folk tradition of "sacred geography" (see **VIIa-2**). The directions defined by these sectors bear little relation to the qiblas of those localities that could be (and had been) computed with an accurate mathematical formula, known since the 9th century, using available geographical data. And just in case, there is a "universal qibla niche" (*miḥrāb āfāqī*) on the meridian "for all latitudes", a reminder that south was sometimes used for the qibla from one end of the Islamic world to the other. Now this primitive scheme is associated with *a highly sophisticated and carefully executed transversal scale* that serves to measure angles with greater accuracy than with a regular scale. This scale was probably inspired by a similar one on a Renaissance European instrument, for the fact that al-Sijzī *ca*. 990 had proposed a transversal scale had been long forgotten, and I am not aware that he was quoted by any later Muslim astronomer. Also, the compass (with a deviation of about 15°) looks as if it is of European inspiration. Ottoman astronomers were probably unaware that the magnetic compass was described in Arabic texts in Egypt and the Yemen *ca*. 1300, although texts were available to them on the first measurements of the deviation by ʿIzz al-Dīn al-Wafāʾī in Cairo *ca*. 1450. This instrument has been studied in Chidyaq, "Indicateur de Qibla". [Courtesy of the Institut du Monde Arabe, Paris.]

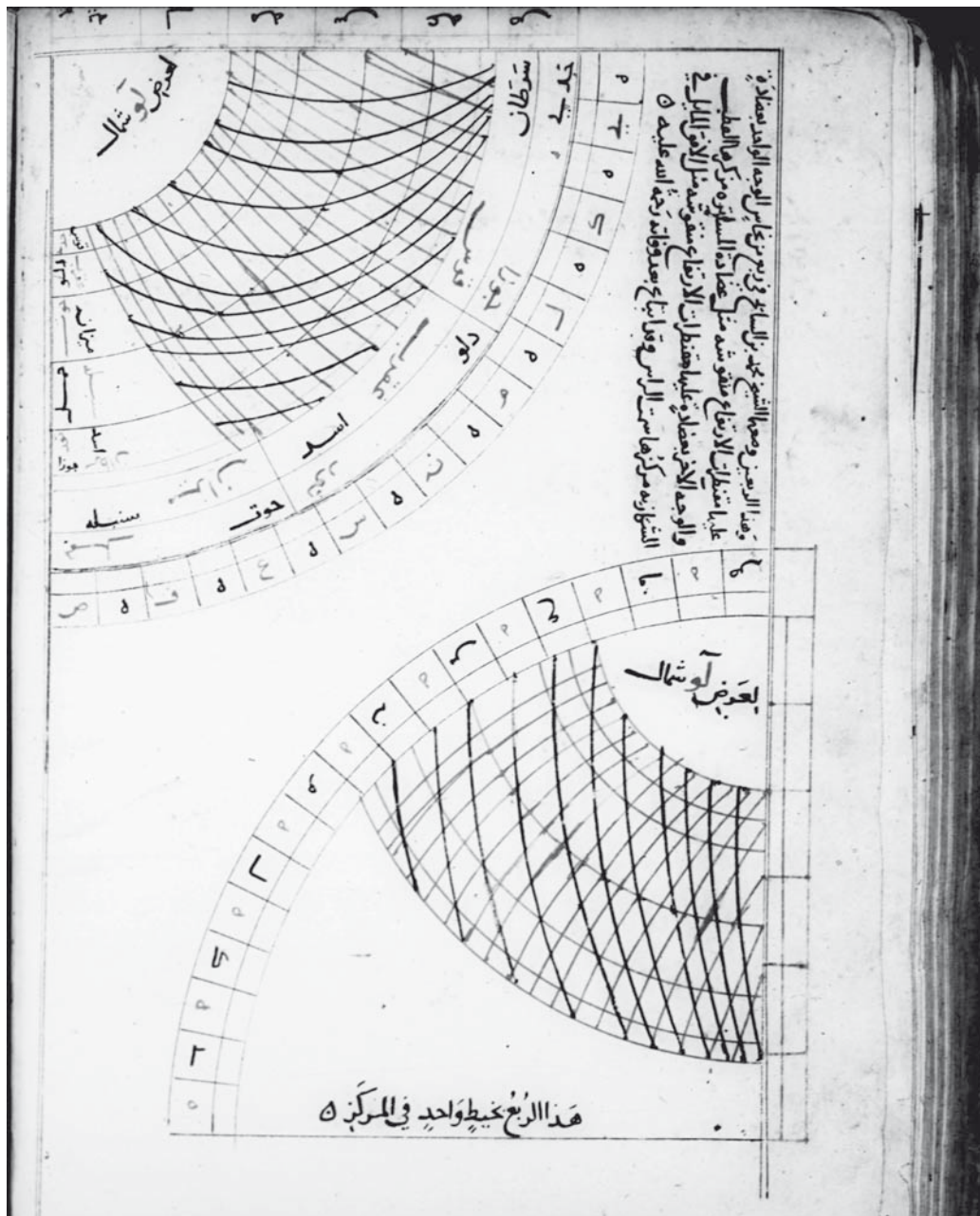



Fig. 1.8: The Egyptian astronomer Najm al-Dīn al-Miṣrī (*ca*. 1325) presented descriptions and illustrations of over 100 different instrument types known to him or invented by him. One of his descriptions of one of the latter is particularly remarkable, indeed brilliant. It is an horary quadrant fitted with azimuth curves (his term *musammat* means just that). Essentially the markings display the solar altitudes and the solar azimuths as functions of time since sunrise and solar declination. A table is provided, and this and the illustration serve latitude 36°, a value favoured for didactic purposes (the middle of the 4th climate, that is, the middle of the inhabited part of the earth). Najm al-Dīn informs us that two examples were made in brass, presumably for the latitude of Cairo, by a certain Muḥammad ibn al-Sāʾiḥ, otherwise unknown to us, and sold after his death. He clearly devised this quadrant in his early years, for his treatise shows signs of him loosing the thread. Najm al-Dīn's treatise is now published by François Charette: on this instrument, see his *Mamluk Instrumentation*, pp. 137-139, also pl. 18 on p. 422. [From MS Dublin CB 102, fol. 96v, courtesy of the Chester Beatty Library.]

all reprinted thanks to the foresight of Professor Fuat Sezgin of Frankfurt, but the reprints were not published in sufficient numbers (80 copies?) and were very soon out of print, scattered mainly in places where there is no interest in instruments anyway, let alone in serious scholarship; thus these volumes are not necessarily to be found in the major research libraries. The quality of the illustrations in these early writings was generally far better than in publications of the late 20th century. Another problem in this field is that—as in the Middle Ages—knowledge has not been cumulative. Even instrument specialists have forgotten what it means to "publish" an instrument: it means to present appropriate illustrations and a detailed description stressing what the piece contributes to our knowledge of the field or posing questions for others to address. And too often the instruments have been at the mercy of those interested only in inscriptions rather than astronomical markings. New publications on individual astrolabes, for example, are of no particular interest or value unless the instruments differ wildly from others described in previous publications. Likewise, modern works that present impressive but uncritical bibliographies on individual instruments tend to forget to mention either when and where the instrument was first published or that, in spite of dozens of honourable mentions, the instrument has in fact never been properly "published" at all.

Our knowledge of Islamic instrumentation took a significant step forward with the publication of Robert Gunther's *Astrolabes of the World* in 1932. But Gunther was not an Arabist and could not read the inscriptions on the Islamic astrolabes he surveyed; furthermore, he was poorly advised by the Arabists at Oxford, whom he consulted on occasion. This had many unfortunate consequences, but the worst was that historians thought he had exhausted the field, and his work has been neither corrected nor updated. Until recently the only descriptions of a few of the available instruments were scattered in learned journals; also many important textual sources are still available only in manuscript form. However, there is currently some scholarly and public interest in this subject, much of which goes back to the insights and aspirations of Derek de Solla Price, who *ca*. 1970 set about taking stock of all known astrolabes (about three times the number known to Gunther). Witness, for example, the first survey of Islamic celestial globes by Emilie Savage-Smith (published in 1985); the long-awaited *Répertoire* of Islamic astrolabists and their works by the late Alain Brieux and Francis Maddison (in press); and my own catalogue of Islamic (and also early European) astrolabes, quadrants and sundials up to *ca*. 1500 (still in preparation). Some of the best descriptions of instruments have been published so far only in auction catalogues of Christie's and Sotheby's.

In this brief overview, I shall illustrate the rich variety of material that will have to be included in the first history of Islamic instrumentation when it is eventually written. I deliberately stress the associated textual tradition, which has generally been overlooked by most scholars who have written on Islamic instruments in the past. On the other hand, some colleagues tend to think that all that is important about astronomical instrumentation is texts on the construction and use of the instruments, and so they tend to ignore the instruments themselves. Some of these colleagues are under the false impression that instrument-makers went "by the book"; in fact the craftsmen showed a great deal of imagination, and some of their modifications to standard instruments are not documented in any known texts. The reader should also bear in mind that it is a somewhat risky business to consider the development of Islamic instrumen-

tation apart from the general development of Islamic astronomy, and this before a survey of medieval instruments and treatises thereon has been completed. However, the time seems ripe for a step in this direction, not least because the history of astronomical timekeeping cannot be written without taking into consideration the astronomical instruments whose primary function was to facilitate timekeeping.

In any case, we perhaps need to be liberated from the notion that Islamic instrumentation is of consequence only as a prelude to European developments in this field. The study of Islamic instruments is but a small chapter in the history of Muslim interest in astronomy for over a millennium. It is already well known that various Islamic instruments and related mathematical procedures were influential in medieval Europe; indeed, instrumentation in medieval and Renaissance Europe can often barely be understood without reference to the Islamic tradition. The instruments were, inevitably, basically the same, because they were needed for the same purposes in each milieu. This is, of course, not to say that do not find occasional innovations in medieval Europe. However, in recent years, it has become increasingly obvious that most of the major technical innovations in Renaissance instruments have their counterparts in earlier Islamic instrumentation. Again, there is no need to assume direct or even indirect borrowing or to exclude independent initiative. However, I think it is important to point out that most of these Renaissance instruments had precedents elsewhere. The weak link is now our knowledge of the medieval European scene, because reliable catalogues are available at least for Renaissance Flemish and English instruments.

Bibliographical notes to Ch. 1: Useful introductory surveys of early astronomical instruments in general are Price, "Precision Instruments to 1500"; Michel, *Scientific Instruments in Art and History*; G. Turner, *Antique Scientific Instruments*; Poulle, "Instruments astronomiques du moyen âge"; and also Bennett, *The Divided Circle*, pp. 7-26. Anthony J. Turner is currently preparing a general work on the history of medieval astronomical instruments and has already published a 'second' volume *Early Scientific Instruments—Europe 1400-1800*, as well as *Mathematical Instruments in Antiquity and the Middle Ages*. See also Maddison, "Early Astronomical Instruments", with a useful bibliography; and *idem*, "Medieval Instruments". On instruments in Antiquity, see the new translation of Ptolemy's *Almagest* by G. J. Toomer, and the overview in Dicks, "Ancient Astronomical Instruments".

On the celestial sphere and armillary 'astrolabe' (as Ptolemy called it) in Antiquity see E. Stevenson, *Terrestrial and Celestial Globes*; and Fiorini, *Erd- und Himmelsgloben*, translated from the Italian by S. Günter; Schlachter, "Der Globus"; and Nolte, "Die Armillarsphäre". More recent publications include Dekker *et al*., *Globes at Greenwich*. For *aficionado*s there is the Vienna-based journal *Der Globusfreund*.

On the origins of the astrolabe see Neugebauer, "The Early History of the Astrolabe". On the instrument itself, see Michel, *Traité de l'astrolabe*; Bruin, "The Planispheric Astrolabe: Its History, Theory, and Use", in *al-Bīrūnī Newsletter* nos. 33, 34 and 35 (1970); North, "The Astrolabe"; Neugebauer, *HAMA*, II, pp. 857-879; *Rockford TM Catalogue*, I:1; and, for a modern mathematical approach, d'Hollander, *L'Astrolabe*, and Morrison, *The Astrolabe*, to appear.

On sundials in Antiquity see Gibbs, *Greek and Roman Sundials*, to which add Buchner, *Die Sonnenuhr des Augustus* (problematic), and now Schaldach, *Römische Sonnenuhren*, and *Antike Sonnenuhren*, I. On sundial theory in Antiquity see Neugebauer, *HAMA*, II, pp. 839-857. See also Higgins, "The Classification of Sundials", A. Turner, "Sundials: History and Classification", and King,

"Towards a History of Sundials from Antiquity to the Renaissance". On early mechanical devices to represent celestial motions see Price, *Gears from the Greeks*; Field & Wright, "Gears from the Byzantines", repr. in *eidem* & Hill, *Byzantine and Arabic Mathematical Gearing*; and King-*père* (with John R. Milburn), *Geared to the Stars*.

Numerous 19th- and early-20th-century publications on specific instruments are available; there are far too many to be listed here. See **Chs. 4-5** on some of the most reliable studies of individual astrolabes and quadrants. A series of six volumes entitled *Arabische Instrumente in orientalistischen Studien* (hereafter *AIOS*) and containing reprints of articles on instruments mainly from the 19th and early 20th centuries has been published by the Institut für Geschichte der Arabisch-Islamischen Wissenschaften in Frankfurt (1990-91). These six volumes are again reprinted in *Islamic Mathematics and Astronomy* (hereafter *IMA*), vols. 85-90 (1998), to which another six volumes have now been added as vols. 91-96 (1998): a monumental total of some 5,000 pages (!). To mention only one of these early studies in which contemporary (1927) knowledge of observational instruments is surveyed, we note the important contribution Wiedemann & Juynboll, "Avicenna's Schrift über ein Beobachtungsinstrument", esp. pp. 81-129. In the main bibliography to this volume, I have generally indicated whether the articles that I cite are reprinted in *AIOS*, but not whether they are reprinted in *IMA*. In case of doubt, the reader should assume that a given article published before the middle of the 20th century *has* been reprinted in Frankfurt.

In its time the best introduction to *Islamic* astronomical instruments, if not the related textual tradition, was Francis Maddison and Anthony Turner's *London SM 1976 Exhibition Catalogue*, privately distributed but unfortunately never published. Since then we have Samsó, "Instrumentos astronómicos", which pays considerable attention to transmission to Europe; *Madrid MAN 1992 Exhibition Catalogue*, of which the same can be said, and which contains a series of essays on different kinds of instruments and is also well illustrated; and Maddison, "Instruments arabes" (in *HSA*, but not in the 1996 English version of *EHAS*). Another study of major importance is Goldstein, "Astronomical Instruments in Hebrew".

Some aspects of instrumentation that have come to light only during the long-term Frankfurt-based project to catalogue all Islamic instruments (and European ones) to *ca*. 1500 are described in King, "Astronomical Instruments between East and West".

Other recent publications dealing with instruments on the one side and the transmission of texts on instruments on the other include various papers reprinted in Kennedy *et al*., *Studies*; Goldstein, *Studies*; King, *Studies*, B; Lorch, *Studies*; and Samsó, *Studies*.

References to the manuscript sources for medieval Arabic, Persian and Turkish treatises on instruments are scattered throughout the standard bio-bibliographical works: Suter, *MAA*; Brockelmann, *GAL*; Renaud, "Additions à Suter"; Krause, "Stambuler Handschriften"; Storey, *PL*; Sezgin, *GAS*; King, *Cairo ENL Survey*; Matvievskaya & Rosenfeld, *MAMS*; and Rosenfeld & İhsanoğlu, *MAIC*.

Most major Islamic treatises on instruments, such as the works of al-Farghānī, al-Sijzī, al-Bīrūnī, and the Sultan al-Ashraf, are unpublished. al-Marrākushī's treatise is available in a photo-offset edition of a fine Topkapı manuscript (Frankfurt: Institut für Geschichte der Arabisch-Islamischen Wissenschaften, 1984); on the two halves of this work see Sédillot-*père*, *Traité*, and Sédillot-*fils*, *Mémoire*, and also Karl Schoy, *Gnomonik der Araber*. François Charette has prepared an edition, English translation and commentary for the treatise of Najm al-Dīn: see his *Mamluk Instrumentation*. Richard Lorch has prepared an edition of the parts of the treatises of al-Sijzī and al-Bīrūnī dealing with non-standard astrolabes, and is currently preparing an edition of the treatise of al-Farghānī.

The history of Islamic instrumentation cannot be considered independently of the history of Islamic astronomy in general. See King, "Islamic Astronomy", for an overview in which instrumentation is

given due attention. Also overviews of the history of astronomy in al-Andalus, the Maghrib, Egypt and Syria, the Yemen, Ottoman Turkey, Iran and Central Asia are now available: for references see King & Julio Samsó, "Islamic Astronomical Handbooks and Tables", pp. 16-17, n. 11.

On the influence of Islamic instrumentation in the European Middle Ages and the reappearance of certain Islamic instrument types in the Renaissance see King, "Astronomical Instrumentation between East and West", pp. 144-145, 154, 156, 161, and 168-169, and some works still in preparation. The latest catalogues of Renaissance instruments are van Cleempoel, *Flemish Instruments*, and G. Turner, *Elizabethan Instruments*. Some remarks on medieval European and medieval Islamic precedents are in my review of the latter, esp. pp. 148-150.

On the Frankfurt facsimiles of historical instruments see the notes to **Ch. 11**.

CHAPTER 2

OBSERVATIONAL INSTRUMENTS

Ptolemy's *Almagest*, available to the Muslims in the 8th century, contained descriptions of the armillary sphere, the meridian quadrant and the parallactic ruler. Muslim scholars and craftsmen made improvements to these instruments: new scales were added, modified versions were devised, and larger instruments were constructed (often when smaller ones would have achieved the same degree of accuracy). Most of the early observational instruments are known to us only from texts which, in the main, are published and accessible. For example, we may cite the treatise by the celebrated early-11th-century philosopher Ibn Sīnā, in which he described an instrument for measuring celestial altitudes. This consists of an elaborate sighting device several metres long which can be moved vertically with respect to a horizontal bar of the same length; the outer end of the horizontal bar can move around a horizontal track on a circular brick wall. This is indeed far more than one would expect from a philosopher! Again, in the introduction to his treatise on construction of astrolabes and sundials the late-13th-century Yemeni Sultan al-Ashraf records that the Fatimid Caliph al-Ḥākim in Cairo some three centuries earlier had an armillary sphere of nine rings, each of which weighed 2000 *raṭl*s (*ca*. 1000 kg) and was large enough that a man could ride through it on horseback. Two equatorial rings constructed in Cairo during the early 12th century had a diameter of 5 and 3.5 metres, but even the latter was found to sag under its own weight; a third with diameter 2.5 metres was finally selected.

We are fortunate to have several treatises dealing with a variety of observational instruments. The 12th-century astronomer al-Khāzinī of Merv in Central Asia described six instruments, including the parallactic ruler, the diopter, an instrument in the form of a triangle (*dhāt al-muthallath*), the meridian quadrant, mirrors (*ālat al-inʿikās*), and the astrolabe. His treatise awaits the study it deserves. His late contemporary al-Samawʾal al-Maghribī also describes several observational instruments with a view to improving the accuracy of altitude measurements; his treatise awaits a doctoral student. The 13th-century Syrian astronomer al-ʿUrḍī has left us an account of the instruments used at the Maragha Observatory in N.W. Iran, where he himself worked. Writing at the Observatory of Samarqand in Central Asia in the early 15th century, al-Kāshī described the triquetum, the armillary sphere (here with seven rings), the equinoctial and solstitial armillary, the so-called *Fakhrī* sextant for making meridian observations, an instrument for measuring both altitudes and azimuths, and another for finding trigonometric ratios. Another treatise by al-ʿĀmilī (*ca*. 1560) deals with the instruments at both the Maragha and Samarqand Observatories. Yet another, by Taqi 'l-Dīn, the director of the short-lived Istanbul Observatory in the late 16th century, deals with the observational instruments used there but alas not with those illustrated in the beautiful miniature of the Observatory reproduced as **Fig. 1.1**. The observational instruments of Taqi 'l-Dīn are, as Sevim Tekeli has shown, identical in conception to those of his near contemporary Tycho Brahe. The

former marked the end of serious observational activities in the Islamic world.

The modern literature on these Arabic, Persian and Turkish texts on observational instruments is scattered and largely inaccessible. A worthwhile task would be the preparation of a comprehensive overview of all the available material, with properly edited texts and reliable translations and a commentary. Any doctoral student who would embark on such a task could count on finding in Oriental libraries new texts relevant to his/her subject unknown to his/her predecessors.

Muslim observational activity has been surveyed in a masterful study by Aydin Sayılı, and the possible, and indeed probable, relationship of the Islamic tradition to later European observational instruments has also been discussed by Sevim Tekeli. Since all of the planetary observations recorded in the known Islamic sources are based on naked-eye observation, we can only assume that instruments such as the armillary sphere—see **Fig. 3.5**—or even simpler combinations of rings were actually employed in serious observation programmes. But only in the case of solar observations to determine the terrestrial latitude and the obliquity of the ecliptic do we read that instruments such as the mural quadrant or a meridian ring were actually used in practice.

An interesting historical question concerns the origin of the torquetum, an instrument known in medieval Europe, which permits measurements in the planes of the celestial equator and the ecliptic as well as the plane perpendicular to the ecliptic and the vertical plane. It is first described in European astronomical texts from the 13th century, and investigations of its relationship with the observational instruments described by Jābir ibn Aflaḥ (known in the West as Geber) in Seville in the early 12th century have led to the conclusion that the torquetum is indeed of European origin.

The sites of the observatories of Maragha and Samarqand have been excavated. Only the foundations of the former remain; of the latter, only the enormous meridian quadrant some 40 metres in radius: see **Fig. 2.1**. From no other Islamic observatories have we any surviving instruments. The stone observatories built in India in the early 18th century, supposedly in the Islamic tradition, are an anomaly: here we have all the instruments but no observation records or original results of any consequence.

Notes: The fundamental study of Islamic observatories is Sayılı, *The Observatory in Islam*, a work that is still of as much value today as it was 40 years ago. On al-Ḥākim's armillary instrument see King, *Astronomy in Yemen*, pp. 28-29, and also Sayılı, *The Observatory in Islam*, pp. 167-172. On the observatories of Maragha and Samarqand see *ibid*., pp. 187-223 and 259-289. On more recent excavations at those two sites see Bruin, "The Astronomical Observatory of Naṣīr al-Dīn al-Ṭūsī", in *al-Bīrūnī Newsletter* 13 (1968); Vardjavand, "Observatoire de Maraqe"; Bruin, "The Astronomical Observatory of Ulugh Beg in Samarqand", in *al-Bīrūnī Newsletter* 9 (1967); and various articles listed in *DSB*, XIII, p. 537 (in the article "Ulugh Beg"). The Istanbul observatory is discussed in Ünver, *İstanbul Rasathanesi*, and Sayılı, *The Observatory in Islam*, pp. 289-305. On the stone observatories in India see Kaye, *The Observatories of Jai Singh*, A-B, and, more recently, Sharma, *Sawai Jai Singh and his Astronomy*.

On early solar observations with meridian quadrants see especially al-Bīrūnī's treatise on mathematical geography called *Taḥdīd* ... , transl. by Jamil Ali, comm. by E. S. Kennedy. Other studies

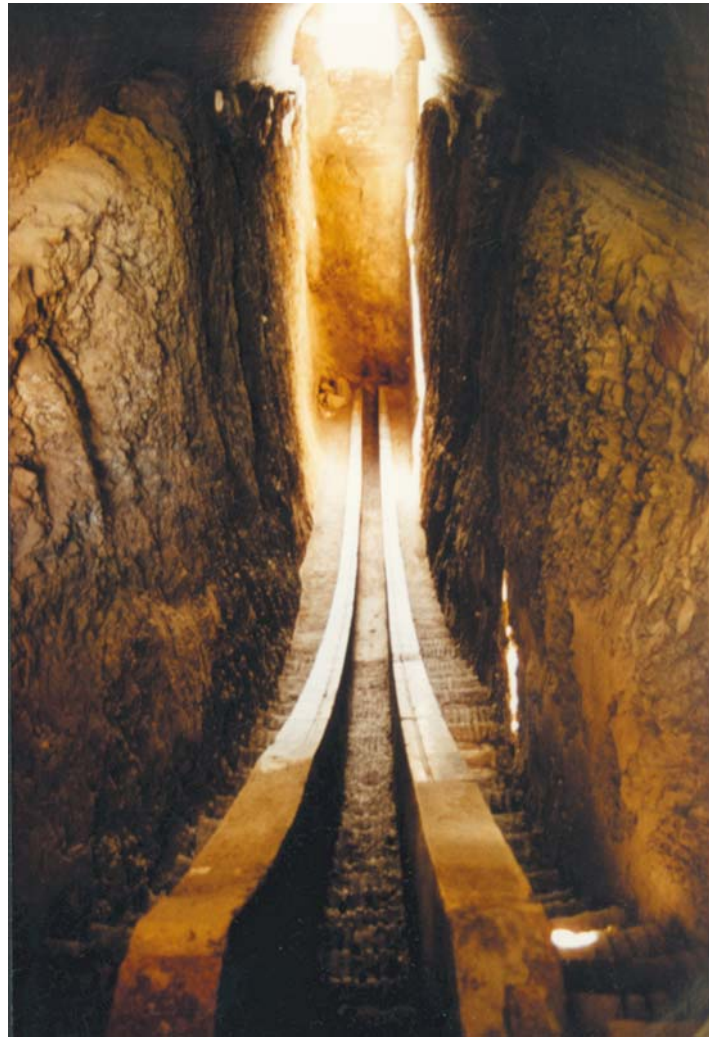



Fig. 2.1: The mural quadrant with radius 40 m at the observatory in Samarqand. [Photo courtesy of Professor Walter Kegel, Frankfurt.]

on observations include Schirmer, "Studien zur Astronomie der Araber: II. Arabische Bestimmungen der Schiefe der Ekliptik", and Renaud, "Déterminations marocaines de l'obliquité de l'écliptique"; and several monographs reprinted in Goldstein, *Studies*. On Ibn Sīnā's instrument see Wiedemann & Juynboll), "Avicenna über ein Beobachtungsinstrument", and also *ZGAIW* 2 (1985), pp. A47-73 (facsimile of the manuscript).

Studies of instruments at individual observatories beyond those discussed in Sayılı, *Observatory*, include: Bruin, "The Fakhrī Sextant in Rayy", in *al-Bīrūnī Newsletter* 19 (1969); Sayılı, "Al-Khāzinī on Instruments"; Bruin, "A Treatise on Small Instruments by ... al-Khāzinī ... ", in *al-Bīrūnī Newsletter* 30 (1970); Seemann, "Die Instrumente der Sternwarte zu Maragha", repr. in *AIOS*, VI, pp. 17-129 (see also the review by Josef Frank repr. *ibid*., pp. 130-141); Tekeli, "al-ʿUrḍī on the Observational

Instruments at Maragha Observatory"; Bruin, "The Observational Instruments of al-ʿUrḍī ... ", in *al-Bīrūnī Newsletter* 10 (1968); *idem*, "The Construction of Instruments ... by ... al-ʿĀmilī ... ", *ibid*. 15 (1968); Kennedy, "al-Kāshī on Instruments"; Tekeli, "The Astronomical Instruments of *Zīj-i-Shāhinshāhīya*", *eadem*, "The Instruments of Taqī al Dīn and Tycho Brahe", and *eadem*, "Observational Instruments of Istanbul Observatory"; Bruin, "The Instruments of Taqī al-Dīn ... ", in *al-Bīrūnī Newsletter* 29 (1970); and Ansari & Ghori, "Two Treatises on Astronomical Instruments". On the torquetum see Lorch, "The Astronomical Instruments of Jābir ibn Aflaḥ and the Torquetum". On the "Jacob's staff" invented by Levi ben Gerson and various other instruments see Goldstein, *The Astronomy of Levi ben Gerson*, chs. 6-9. Sezgin, "Jakobsstab" (in Arabic), is confused.

CHAPTER 3

CELESTIAL GLOBES AND ARMILLARY SPHERES

The problems of spherical astronomy can be illustrated by means of a three-dimensional celestial globe. The stars and the ecliptic, the apparent path of the sun against the background of fixed stars, are represented on the outside of a sphere of arbitrary radius which is set inside a horizontal ring representing the local horizon. The axis of the sphere is fixed in the plane of the meridian, and its inclination to the horizon can be adjusted so that the ensemble represents the heavens with respect to the horizon of any locality. One rotation of the sphere about its axis corresponds to one 24-hour period of time. As the body of the heavens is represented by the celestial globe, so its skeleton is represented by the armillary sphere, consisting of a series of rings for the celestial equator, the ecliptic, the meridian and an adjustable horizon.

The Muslims inherited the celestial globe from the Greeks, and a description of such an instrument was available to them in Ptolemy's *Almagest*. Of considerable historical interest to the problem of transmission is the celestial map on the inside of a dome in the early 8th-century architectural complex known today as Quṣayr ʿAmra in Trans-Jordan: it shows a strange mixture of ecliptic and equatorial coordinates, with some constellations incorrectly represented. The aspect is not that of the sky in nature but rather the sky as portrayed on a celestial globe (such as is also found on the planispheric astrolabe)! Also Near Eastern influences can already be detected in the figures. The 10th-century astronomer al-Ṣūfī of Shiraz informs us that he found illustrations of the constellations in a (now lost) treatise by the 9th-century scholar ʿUṭārid ibn Muḥammad al-Ḥāsib and on a large globe by the latter's contemporary, (the elusive) ʿAlī ibn ʿĪsā. al-Ṣūfī's own illustrated treatise on the constellations was to become the leading work on the subject, if not the only one. One Ibn al-Sanbadī, when visiting the library in Cairo in 435 H [= 1043/44], saw a silver globe made by al-Ṣūfī himself for the Buwayhid ruler ʿAḍud al-Dawla, weighing 3,000 *dirham*s and which had been purchased for 3,000 *dīnār*s.

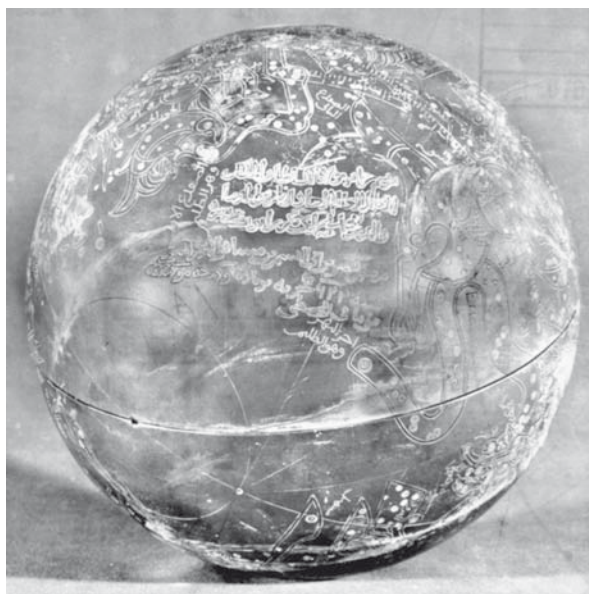
Several Arabic treatises were written on the celestial globe over the centuries. The instrument was called in Arabic *al-kura* or *al-bayḍa* or *dhāt al-kursī*, terms meaning "the sphere", "the egg-shaped (!) instrument" and "the instrument resting in a horizontal frame". Some 200 Islamic celestial globes have been surveyed (but alas generally not illustrated) by Emilie Savage-Smith, who established that there are three main kinds: those with outlines of constellation figures and numerous stars; those showing only the brightest stars and no constellation figures; and those marked only with a spherical coordinate system. See **Figs. 3.1-4** for three fine examples: a task for the future is to assemble a photographic archive of all surviving early globes. A particularly interesting globe, devised by al-Khāzinī in the early 12th century and known to us only from a description, could be made to rotate by means of a falling weight attached to its axis through a gear-and-pulley arrangement. Only a few late Islamic

armillary spheres survive, although several treatises on the *dhāt al-ḥalaq*, "the (instrument) with the rings" were compiled over the centuries: see **Fig. 3.5**.

A hemispherical instrument reflecting the celestial motion was devised by the 10th-century astronomer and instrument-maker al-Khujandī, and this was made universal by his successor Hibat Allāh al-Asṭurlābī in the early 12th century. This instrument seems to have provided the inspiration for the huge hemispherical bowl instruments of the much later Indian stone observatories. The manuscripts await study: see **Fig. 3.6**.

The celestial map at Quṣayr ʿAmra is studied in Beer, "Astronomical Dating of Works of Art", (in *Vistas in Astronomy* 9 (1967), pp. 177-223), esp. pp. 177-187, with notes by Willy Hartner *ibid*., p. 225. A survey of Islamic celestial globes is Savage-Smith, *Islamicate Celestial Globes*. (For some corrections and comments see the review by Paul Kunitzsch in *Der Islam* 64 (1987), pp. 367-370, and my review in *Isis* 81 (1990), pp. 762-764.) That study alas did not present many decent illustrations of historically important (that is, early) Islamic globes. Earlier studies of individual globes include: Assemani, *Globus arabicus*, 1790; Meucci, *Globo celeste arabico*, 1878; Dorn, "Drei arabische Instrumente", 1865, esp. pp. 31-63; and Pinder-Wilson, "The Malcolm Celestial Globe", 1976. For treatises see Worrell, "Qusṭā ibn Lūqā on the Celestial Globe"; Kennedy, "Al-Ṣūfī on the Celestial Globe"; Lorch, "al-Khāzinī's 'Sphere that Rotates by Itself'", *idem*, "The *sphaera solida*", and *idem* & Kunitzsch, "Ḥabash on the Sphere", all three repr. in Lorch, *Studies*, XI-XIII. On the hemispherical instrument of al-Khujandī (called *al-āla al-shāmila*) see Frank, "Zwei arabische Instrumente", and Rosenthal, "Al-Asṭurlâbî and as-Samawʾal on Scientific Progress", esp. pp. 557-560. On an early-10th-century treatise on the armillary sphere see Stern, "A Treatise on the Armillary Sphere by Dunas ibn Tamīm".

Fig. 3.1: Some of the markings on the splendid globe (#6001), a mere 21 cm in diameter, made by Ibrāhīm ibn Saʿīd al-Sahlī in Valencia in 473 H [= 1080]. The piece was published by Ferdinando Meucci in 1878 and has barely been studied since. For an unsigned globe in the Bibliothèque nationale de France by the same maker (#6034) see *Madrid & New York 1992 Exhibition Catalogue*, pp. 378-379. [Courtesy by of the Museo di Storia della Scienza, photo by Franca Principe, proving that even 3-dimensional instruments can be photographed properly by an expert.]

Fig. 3.3: Part of the magnificent celestial globe (#6002) by Yūnus ibn Ḥusayn al-Aṣṭurlābī made in 539 H [= 1144-45], of which no photos have ever been published. Alas, this one is marred by the absurd early modern stand. [From the archives of Alain Brieux, courtesy of Dominique Brieux. Present location unknown. Formerly in the collection of Marcel Destombes, Paris, but not now in the Institut du Monde Arabe along with his other instruments.]

a

b

Fig. 3.4: A celestial globe from 13th- or 14th-century Iran (#6133) that has recently come to light. Each Islamic globe from before about 1500 should be published again, with proper illustrations. [Courtesy of Tartu University Museum, Estonia.]

Fig. 3.5: An illustration of an armillary sphere on the cover of the unique copy of the auxiliary tables for solving problems of spherical astronomy by the 15th-century Cairene astronomer al-Wafāʾī. The various observations recorded by Muslim astronomers were made with instruments far simpler than this, and indeed the majority of planetary conjunctions and eclipses of which we have written accounts appear to have been observed with the naked eye. All that one needs in order to determine the time of an observation is an instrument for measuring celestial altitude: the time can then be *calculated* more accurately than it can be *measured* on any medieval instrument. [From MS Vatican Borg. arabo 817, fol. 1r, courtesy of the Biblioteca Apostolica Vaticana.]

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Figs. 3.2a-b: Two views of a celestial globe made in 622 H [= 1225] (#6003) by the celebrated Egyptian scholar ʿAlam al-Dīn Qayṣar (see **Fig. XIVa-3.6**). In the first we see Perseus, Taurus (head spans two halves of globe), Orion and Lepus down the centre, and Gemini off to the right; in the second the maker's inscription and dedication to the ruling Mamluk sultan near to the inevitable void of the sky around the southern pole. This magnificent object, a mere 22 cm in diameter, was published in a book of about 250 pages by the orientalist Simon Assemani (Fück, *Arabische Studien in Europa*, p. 125) in 1780. Leo A. Mayer in 1956 listed half a page of references to this precious instrument, without stressing that it had been properly published almost two centuries previously. Emilie Savage-Smith had not a good word for poor Assemani or for his "rather poor facsimile", but inevitably presented no new illustrations. Fuat Sezgin has recently reprinted Assemani's book (*IMA*, vol, 91), which any future researcher would do well to take seriously. I present two old photos of the globe: somehow people were able to take better photos of globes at the beginning of the 20th century than at the end. [Original in the Museo Nazionale, Naples; aged photos from the archives of the late Alain Brieux, courtesy of Dominique Brieux, Paris.]

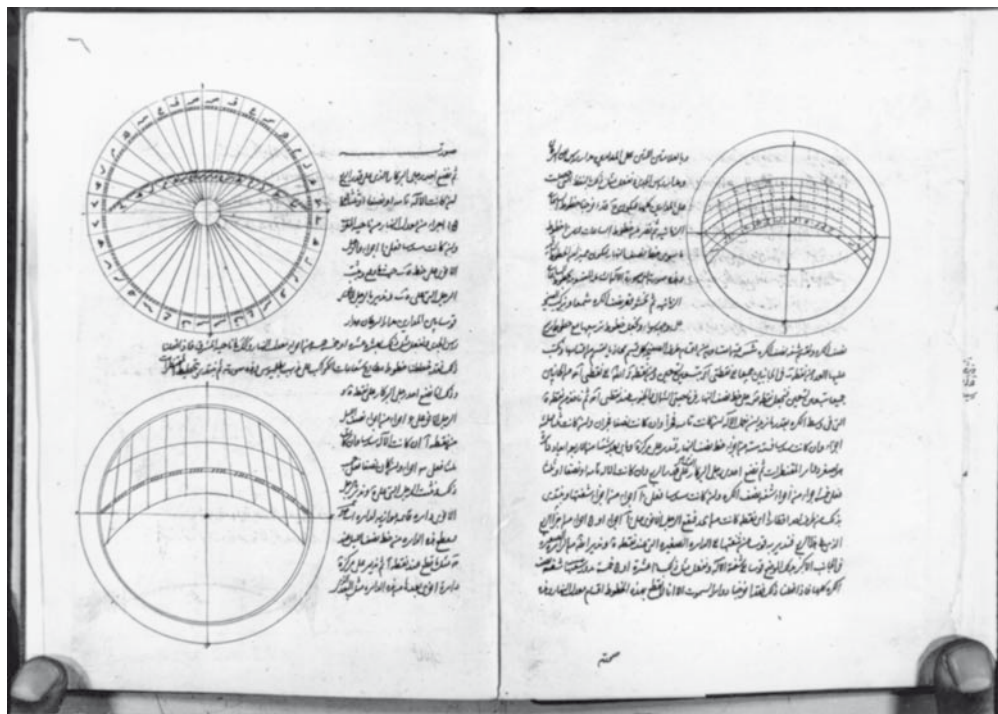



Fig. 3.6: Simplified diagrams of al-Khujandī's hemispherical instrument in a late collection of texts, datable to Meshed *ca*. 1800, containing unique copies of several important Abbasid treatises on instruments (compare **Fig. XIIa-2a**!). [From MS Cairo DM 970, fols. 5v-6v, courtesy of the Egyptian National Library. (MSS Cairo DM 969 and 970 are both by the same copyist.)]

CHAPTER 4

STANDARD PLANISPHERIC ASTROLABES

4.1 On standard astrolabes

The theory of stereographic projection, developed by Hipparchus of Rhodes *ca*. 150 B.C., enables the same problems of spherical astronomy to be solved with equal facility and with but a slight stretching of the imagination by means of a two-dimensional instrument. The Muslims inherited such a device—the planispheric astrolabe—from their Hellenistic predecessors, and they developed it in virtually all conceivable ways. The device results from a stereographic projection of the celestial sphere onto the plane of the celestial equator from the south celestial pole. This projection has the property that circles on the sphere project into circles on the plane and that angles between great circles are preserved.

The standard astrolabe—see **Fig. XIIIa-1.1**—consists of two main parts, one 'celestial' and the other 'terrestrial'. First, there is a grid called a rete, bearing pointers representing the positions of certain prominent fixed stars and a ring representing the ecliptic. Second, there is a plate for a specific latitude bearing markings representing the meridian and the local horizon. Curves showing the altitude (sometimes called *almucantar*s), and an orthogonal set showing the azimuth, are also included on the plate. When the rete—the 'celestial' part—rotates over the plate—the 'terrestrial' part, the apparent rotation of the sun and stars across the sky above the horizon of the observer is simulated. The typical medieval astrolabe contained several plates for a series of latitudes as well as various markings on the back of the instrument either for measuring celestial altitudes or for performing trigonometric calculations. Literally dozens of treatises on the use of the astrolabe were compiled between the 9th and the 16th century, and hundreds of astrolabes survive, including a few dozen from those earliest centuries. These early astrolabes have recently been investigated in Frankfurt, the majority for the first time. Muslim developments to the simple planispheric astrolabe are of considerable historical interest. Also the development of the astrolabe in medieval Europe cannot be understood without recourse to Islamic instrumentation, as several recent studies of early European astrolabes clearly demonstrate.

Sometimes retes were simplified. For timekeeping by the sun one only needs the zodiacal ring. On the Maghribi instrument shown in **Fig. 4.1.5**, an ecliptic ring with a few star-pointers attached will suffice. The maker of the Iranian instrument shown in **Fig. 4.1.6** provided a disk for the ecliptic but no more than a horizon for latitude [36°] and a meridian scale: with this one can do little more than ascertain the horoscopus when the sun is at midday. A set of altitude circles would have rendered his instrument adequate for all timekeeping operations with the sun.

Fig. 4.1.1: The front of an astrolabe made by Badr, *mawlā* of the celebrated Hibatallāh al-Aṣṭurlābī, in 525 H [= 1130/31] (#2557), probably in Baghdad, though possibly in Rayy. This astrolabe is remarkable in that it is a close copy of the astrolabe of al-Khujandī, made about 150 years previously: see **XIIIc-9**. This already shows remarkable developments over the earliest Islamic astrolabes. See **Fig. 4.7.3** for the back. [Courtesy of the Adler Planetarium, Chicago.]

Fig. 4.1.2: The front of an astrolabe made by Muḥammad ibn Ḥāmid ibn Maḥmūd al-Iṣfahānī in 556 H [= 1161] (#1177). The rete design shows minor developments to the earliest astrolabes from the 9th and 10th centuries, yet the lower equinoctial bar and its supports are too broad to be classified as elegant. The plate below the rete is not inserted properly. See **Fig. 4.4.2** for a more unusual plate. The back bears nothing more than a simple trigonometric grid and shadow scales. [Courtesy of the Türk ve Islâm Eserleri Müzesi, Istanbul.]

Fig. 4.1.3: The front of an Andalusī astrolabe (#116), made in Toledo in 420 H [= 1029/30] by Muḥammad ibn al-Ṣaffār. The plates for Toledo and Cordova, as well as the back, have additional later markings in Hebrew: see **Fig. XV-15**. The distinctive style of the star-pointers led to the star-names being a bit tight. In fact, when an instrument of this design was copied in Renaissance Italy (see **Fig. 4.1.4**), the names for the spikey star-pointers on the horizontal axis were omitted altogether. [Courtesy of the Deutsche Staatsbibliothek (Preußischer Kulturbesitz), Berlin.]

→

Fig. 4.1.5: The simplified rete on a late Maghribi astrolabic plate for the latitude of 34° [Meknes] (#4303). Although two of the star-pointers are broken, there is no need to suppose that anything else is missing. It is extremely difficult to date unsigned and undated Maghribi astrolabes (the engraving changed little over many centuries), and I suggest *ca*. 1500 for this piece, even though the throne is reminiscent of al-Khamāʾirī *ca*. 1200 and the equinox on the calendrical scale on the back (see **Fig. XIIa-B7**) is at March 14, which corresponds to *ca*. 1300. [Courtesy of the Victoria and Albert Museum.]

Fig. 4.1.6: If one simplifies the instrument too much it becomes very limited in its application. The markings on the back of this astrolabic plate (#4203), showing the directions to Mecca and Kerbala, indicate that it was made in Hamadan (see **Fig. 4.5.4** and King, *Mecca-Centred World-Maps*, pp. 105-106). [Courtesy of the National Maritime Museum, Greenwich.]

Fig. 4.1.4: The rete of a Renaissance Italian astrolabe (#4507), which has been inappropriately dubbed a fake, not least because of its gilt finish. One thing is clear: the star-pointers on the rete were inspired by a rete in the tradition of Muḥammad ibn al-Ṣaffār (compare **Fig. 4.1.3**). Equally clear is the fact that the Italian who made this piece had no idea which stars he was representing on his rete. [Object in the Museo Bargello, Florence; photo courtesy of the Museo di Storia della Scienza, Florence.]

4.1.5.

4.1.6.

On the astrolabe in the Islamic context we have the masterly overview of Willy Hartner, “The Principle and Use of the Astrolabe”, and his shorter article “Asṭurlāb” in EI_2. **XIIIa** is a new introduction to the astrolabe to supplement Hartner’s more theoretical approach. On the diversity of problems which can be solved with an astrolabe see Destombes & Kennedy, “al-Ṣūfī on the Astrolabe”; Charette & Schmidl, “al-Khwārizmī on the Astrolabe”, forthcoming, replacing Frank, “al-Khwārizmī über das Astrolab”, repr. in *AIOS*, IV, pp. 125-159, with a review by Carl Schoy repr. *ibid*, pp. 160-161; and Viladrich, *Ibn al-Samḥ on the Astrolabe*.

On the origin of the astrolabe see Neugebauer, “The Early History of the Astrolabe”; and on Arabic accounts of its origin, mainly fictitious, see King, “On the Origin of the Astrolabe according to the Medieval Islamic Sources”, now in **XIIIe**. On stereographic projection see, for example, Michel, *Traité de l’astrolabe*, *passim*, and Lehr, *De Geschiedenis van het Astronomisch Kunstuurwerk*, pp. 111-122. On the theory of the markings for the seasonal hours see now Hogendijk, “Seasonal Hour Lines on Astrolabes and Sundials”.

Numerous Islamic astrolabes are presented in Gunther, *The Astrolabes of the World*, vol. I. See Price *et al*., *Astrolabe Checklist*, for brief listings of many more. Their makers are listed in Mayer, *Islamic Astrolabists*, and supplement. More information on signed astrolabes is anticipated in Brieux & Maddison, *Répertoire des facteurs d’astrolabes et de leurs œuvres*, arranged alphabetically by maker. Some valuable studies of the astrolabes in individual collections are Kaye, *Observatories of Jai Singh*, especially chs. III-V; García Franco, *Astrolabios en España*; Dube, “Astrolabes in Rampur”, now replaced by Sarma, *Rampur Catalogue*; [Maddison], *Oxford MHS Billmeir Supplement Catalogue*; Gibbs & Saliba, *Washington NMAH Catalogue*; A. Turner, *Time Museum Catalogue*, I:1; King in *Paris IMA 1993-94 Exhibition Catalogue*, pp. 432-443 (see now **XIVb**); *idem*, “Nürnberger Astrolabien” (includes some Islamic astrolabes—see, for example, **XIVb-2**), and *idem*, “Kuwait Astrolabes” (see now **XIIIc**); and Stautz, *Munich Astrolabe Catalogue* (in German) (some Islamic instruments). On the problems of the treatment of instruments in the imposing volumes listed as *London Khalili Collection Catalogue*, see see my essay review “Cataloguing Medieval Islamic Astronomical Instruments”. Other useful collections of descriptions are in various auction catalogues, particularly that of the Linton Collection, namely, *Linton Collection Catalogue*.

The best study in English of an individual instrument is Morley, “Astrolabe of Shāh Ḥusayn” (1856), appropriately repr. as the introduction to Gunther, *Astrolabes*, I. Other detailed studies are Sédillot-*fils*, “Mémoire” (1844), pp. 172-181; Sarrus, “Astrolabe marocain” (1850); Woepcke, “Arabisches Astrolabium” (1855); Dorn, “Drei arabische Instrumente”, pp. 26-31; Frank & Meyerhof, “Mogulisches Astrolab” (1925); and, more recently, Helmecke, “Berliner Astrolab des Muḥammad Zamān”; Marra, “Due astrolabi ispano-moreschi”; and King, “Yemeni Astrolabe”, now in **XIVa**; *idem*, “Kuwait Astrolabes”, pp. 78-89 (astrolabes of Nasṭulus and al-Khujandī—see now **XIIIc-3a** and **9**); *idem*, “Monumental Syrian Astrolabe”, (1996-97), now in **XIVc**; and Ackermann, “Umarbeitung eines Astrolabs”, and Schmidl, “Ein Astrolab aus dem 17. Jahrhundert”, both summarized in **XIIIa-6**. Some early descriptions are particularly useful now that the instruments described have been stolen: see, for example, Mortillaro, “Astrolabio arabo del nono secolo” (1848) and Caldo, “Astrolabi di Palermo” (1936)—see now **XIIIc-8.1**. On a Renaissance Italian drawings of an early Islamic astrolabe see Saliba, “Astrolabe by Khafīf”, and now **XIIIc-1.3**.

The accuracy of the star positions on various retes is investigated in Stautz, *Mathematisch-astronomische Darstellungen auf mittelalterlichen Instrumenten*. On an earlier study listed as Torode, “Dating Astrolabes”, see the criticism in Dekker, “Astrolabes and Dates and Dead Ends”. Some of the problems of Stautz’ work relating to medieval European astrolabes are identified in Dekker, “Astrolabe Stars”, but usually with Islamic astrolabes, the names are unambiguous and the positions reasonably accurate. The procedure adopted in Firneis, “Granada Astrolabe”, for investigating the accuracy of the markings on astrolabe plates is also problematic, and the results incorrect.

For the stars marked on astrolabes, if only according to the most important medieval textual source, see Kunitzsch, “Al-Ṣūfī and the Astrolabe Stars”. With the exception of Kunitzsch’s observations on

certain 11th-century Andalusī astrolabes, the selection of stars on surviving Islamic astrolabes has yet to be investigated.

The geographical information explicit and implicit that can be extracted from early Islamic astrolabes is presented in King, "The Geography of Medieval Astrolabes", for which see now **XVI**.

On the astrolabe in the textual tradition of one particular region see Sarma, "Sulṭān, Sūri and the Astrolabe", with textual descriptions of actual instruments from 14th-century Delhi that are now lost; *idem*, "Astronomical Instruments in Mughal Miniatures"; *idem*, "The Astrolabe in Sanskrit"; and Plofker, "The Astrolabe and Spherical Astronomy in Medieval India".

On problems of transmission to Europe see van der Vyver, "Les premières traductions latines de traités arabes sur l'astrolabe"; Kunitzsch, "Messahalla on the Astrolabe", and *idem*, "Al-Khwārizmī as a Source for the *Sententie astrolabii*"; and Martí & Viladrich, "Tratados de astrolabio".

4.2 Astrolabe construction

The basic mathematical markings on the astrolabe and those on the various plates for different latitudes can be achieved by geometrical construction. But the Muslims had a passion for compiling tables, and they also realised that tables could facilitate the construction of astrolabes. One needs to know, for example, the radius of each of the altitude and azimuth circles and the dis-

a

b

Figs. 4.2.1a-b: Tables for constructing the altitude and azimuth circles on astrolabe plates from the corpus of al-Farghānī. The functions tabulated here are, on the left, the radii and centre-distances of the altitude circles for latitude 21°, and, on the right, the same for the azimuth circles for latitudes 15°-21°. See **Figs. XIVa-3.5a-b** for some other later tables of this kind. [From MSS Berlin Ahlwardt 5790, fol. 36r (a), and 5791, fol. 42v (b), courtesy of the Deutsche Staatsbibliothek.]

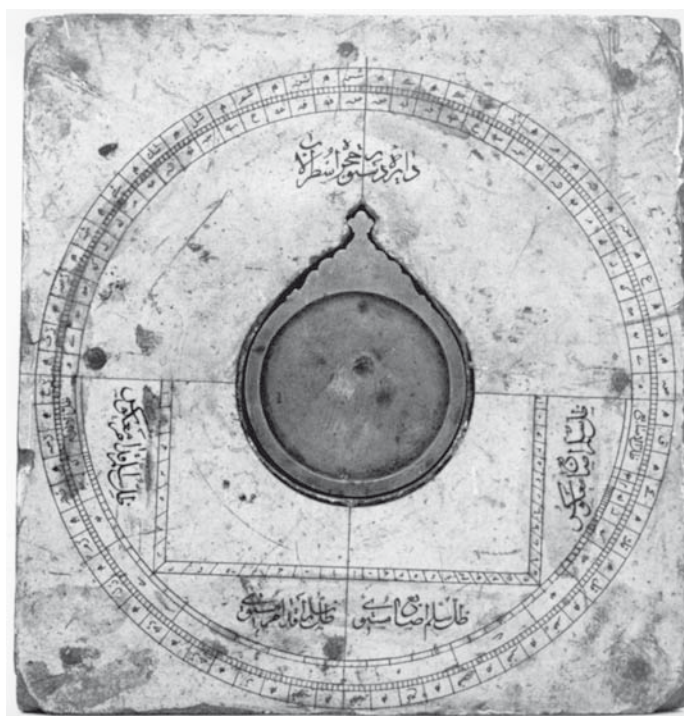



Fig. 4.2.2: A template for astrolabe construction (#8105), with a blank mater that has waited some two centuries to be engraved. Reduction of the larger markings to the smaller scales of the instrument still calls for a complete mastery of the art. [Courtesy of the Museum for the History of Science, Oxford.]

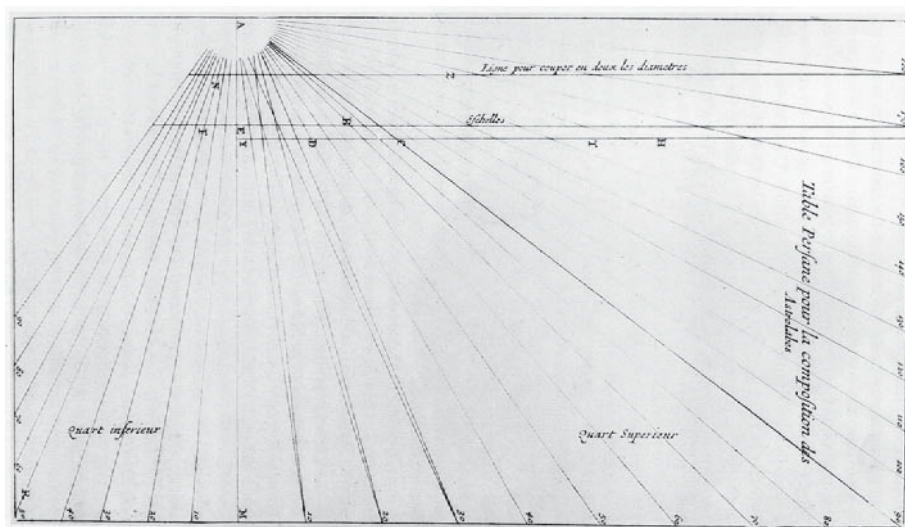



Fig. 4.2.3: This diagram, published by Chardin in his *Voyage en Perse* (Amsterdam, 1735), shows a *dastūr*, which he said the astrolabists of Isfahan had engraved on a rectangular piece of brass a foot long and an *ecu* thick. With such a device, one can derive the tangents of half an arc, essential in the calculation of the size and positions of the ecliptic and altitude circles. For more details, see Michel, "Construction des astrolabes persans", and *Rockford TM Catalogue*, p. 24. [Photo from the archives of the author.]

tances of the centres of these circles from the centre of the astrolabe. In early-9th-century Baghdad, the astronomer al-Farghānī compiled a set of tables displaying the radii and centre distances of both altitude and azimuth circles for each degree of altitude and each degree of azimuth, for each degree of terrestrial latitude. These tables, which contain over 13,000 entries (**VIa-9**, illustrated, and also **Figs. 4.2.1a-b**), were used by astrolabists alongside geometrical construction in the following centuries, and similar but less extensive tables were prepared for specific localities by a series of later astronomers: see **Fig. XIVa-3.4**. This Islamic tradition of compiling tables for astrolabe construction was apparently unknown in medieval Europe. As for marking the basic scales on the rims of the front and back and on the shadow squares and outer shadow scales, we are fortunate to have a late Iranian template ready for use: see **Fig. 4.2.2**. For the markings on the rete and plates, we are likewise fortunate to have an account by Jean Chardin as to the way in which astrolabists of Isfahan did this: see **Fig. 4.2.3**. al-Farghānī might have laughed at their method, but the Isfahan astrolabists produced very accurate astrolabes without using his tables.

On the geometric construction of astrolabes see Charette & King, "Survey of Islamic Tables for Astrolabe Construction", to appear; and already King & Samsó, "Islamic Astronomical Handbooks and Tables", pp. 91-92. The mathematics underlying the tables is found already in Michel, *Traité de l'astrolabe*, pp. 62-63 (although Michel did not realize he had any Muslim predecessors for his elegant trigonometric procedures); see also *idem*, "Construction des astrolabes persans". See also Anagnostakis, "Astrolabe Ecliptic Divisions"; Berggren, "Ḥabash's Analemma for Azimuth Curves"; *idem*, "Drawing Azimuth Circles", and *idem*, "al-Kūhī on Astrolabe Construction". Richard Lorch is currently completing an edition and annotated translation of al-Farghānī's treatise on astrolabe construction.

4.3 Ornamental retes

The Muslims developed the retes of astrolabes into objects sometimes of great beauty. Stars were sometimes selected for inclusion on the retes by virtue of their positions in order to achieve symmetry about the vertical axis. Zoomorphic representations for constellations or groups of stars, or even for single stars, were used, albeit not commonly, from the 10th century onwards. Floral patterns were particularly popular on Iranian and Indo-Iranian astrolabes from the 16th century onwards.

It is now possible to trace the astronomical and artistic development of astrolabe retes. Particularly important were the instruments of al-Khujandī of Baghdad in the 10th century, which broke away from the earliest, rather spartan, retes inherited from the Hellenistic tradition and introduced quatrefoils and zoomorphic figures—see **Figs. 4.3.1-4**; those of al-Khamāʾirī in early-13th-century Seville (**Fig. 4.3.2**), which were imitated in the Muslim West for six centuries; those of ʿAbd al-Karīm al-Miṣrī in Damascus *ca*. 1225 (**Fig. 1.4**), which may have influenced those of Jalāl al-Kirmānī of Central Asia in the 15th century (**XIVd**), which in turn mark the beginning of the floriated patterns on Eastern Islamic instruments and also influenced the school of 17th-century Lahore. The "Gothic" "rectangular-frame" and "quatrefoil" retes on early European astrolabes owe their inspiration to the Islamic tradition (**XVII**).

To give a specific example of transmission of a different kind of rete-design, we note that the astrolabe illustrated in intense detail in the intarsia of the studiolo of Archduke Frederico da

Fig. 4.3.1: The rete of an astrolabe (#137) by al-Sahl al-Nīsābūrī, datable between *ca*. 1180 and *ca.* 1280, with numerous circus figures representing constellations. The star-positions on this spectacular piece can be dated *ca*. 600±100, so that it is to all intents and purposes completely useless from a serious practical point of view: see further **XIVb-2** and compare **XIIIb-3.7**. [Courtesy of the Germanisches Nationalmuseum, Nuremberg.]

Fig. 4.3.2: The rete and limbus are all that survive of this astrolabe (#4148), which by virtue of its design and craftsmanship can be attributed to the prolific Muḥammad ibn Fattūḥ al-Khamāʾirī of Seville, *ca*. 1200. Andalusī retes are distinguished by the counter-changed horizontal bar and the elegant star-pointers, as well as the circular and pear-shaped frames supporting the lower equinoctial bar, although sometimes *miḥrāb*-shaped frames were preferred. [Present location unknown; photo courtesy of Christie's of London and a former owner.]

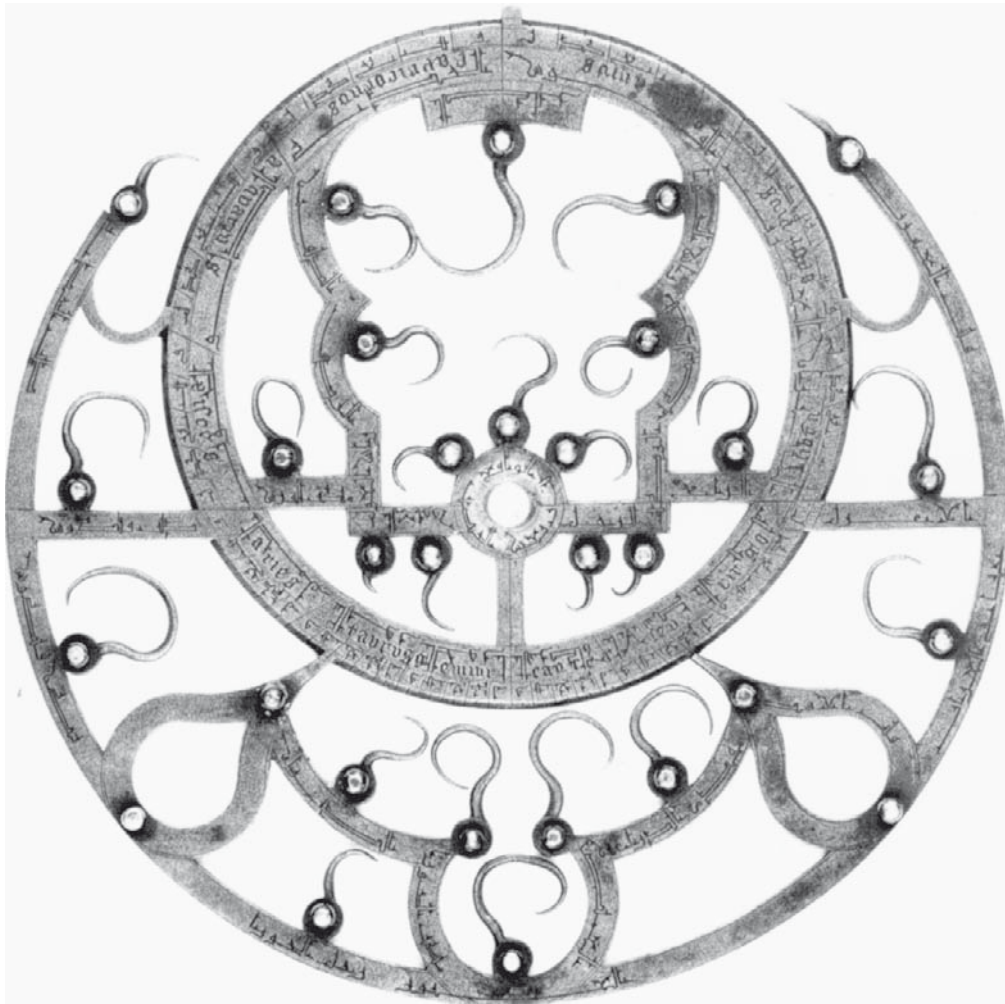



Fig. 4.3.3: This rete is from an astrolabe by the prolific Abū Bakr ibn Yūsuf of Marrakesh, dated 605 H [= 1208/09] (#124). The design is basically similar to contemporaneous Andalusī retes: notice the counter-changed horizontal bar, and the broken circular and pear-shaped frames. The star-pointers, however, are of an original design. It might be thought that they could be easily adjusted for changing star-positions, but this would be more difficult than it might seem. This rete bears later markings by a European. The design was influential in medieval Italy, although the frames in the upper part of the ecliptic were then reversed: see **Figs. XIIIa-10.4a-c**. [Courtesy of the Observatoire de Strasbourg.]

Montefaltro in Urbino (*ca*. 1476) owes its inspiration to a medieval Italian astrolabe-design (attested on an instrument preserved in Florence) inspired by that of Abū Bakr ibn Yūsuf, a prolific and highly-competent instrument-maker in Marrakesh *ca*. 1200. Further evidence of the transmission is found in the identical distinctive design of the thrones on Abū Bakr's astrolabes and the medieval Italian astrolabe. It seems likely that transmission occured via Sicily, but Urbino was not the end of the road, for the Italian rete-design was still in use in Germany in the early 16th century (with Johannes Stöffler).

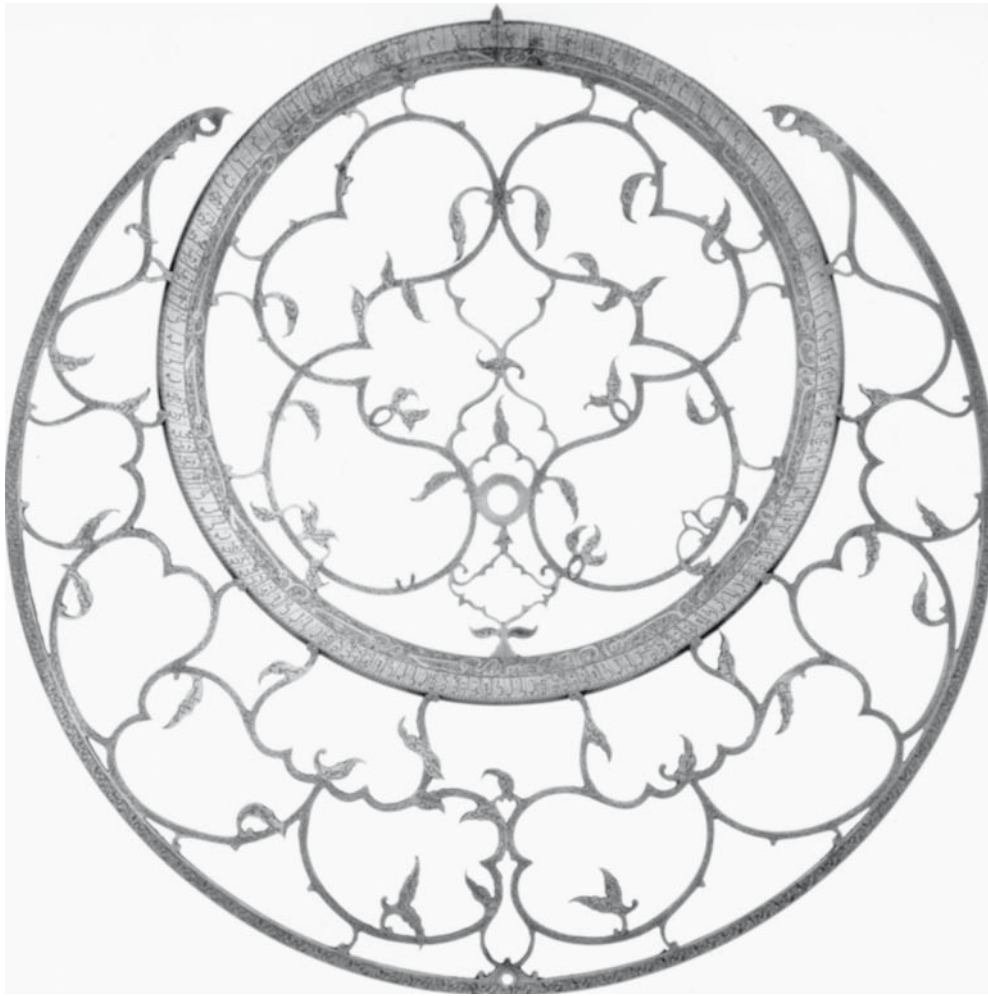



Fig. 4.3.4: The rete of one of the more sophisticated late Iranian astrolabes (#33), made for the Safavid Shāh Ḥusayn in 1124 H [= 1712/13] by ʿAbd al-ʿAlī and engraved by his brother Muḥammad Bāqir. This is the astrolabe that was studied in detail by William Morley in 1856. [Courtesy of the British Museum, London.]

Astronomically-significant decorations of astrolabe retes are investigated in Gingerich, "Zoomorphic Astrolabes", but neither the author nor the editors of the *Kennedy Festschrift* in which the article appeared were aware of the as-yet-then-unpublished early Islamic astrolabes with such markings, and there is more to be said on this subject. On quatrefoil decoration on astrolabes see King, *The Ciphers of the Monks*, pp. 380-390, and now **XVII**. On the possibility of a Syrian origin for the upper bar across the solstitial axis on medieval French astrolabes rete see *ibid*., p. 395, and now **XIVc**.

4.4 On the geography of astrolabes

Geographical and astrological information was often engraved on the maters or plates of astrolabes. Originally astrolabe plates served each of the seven climates of Antiquity (seven

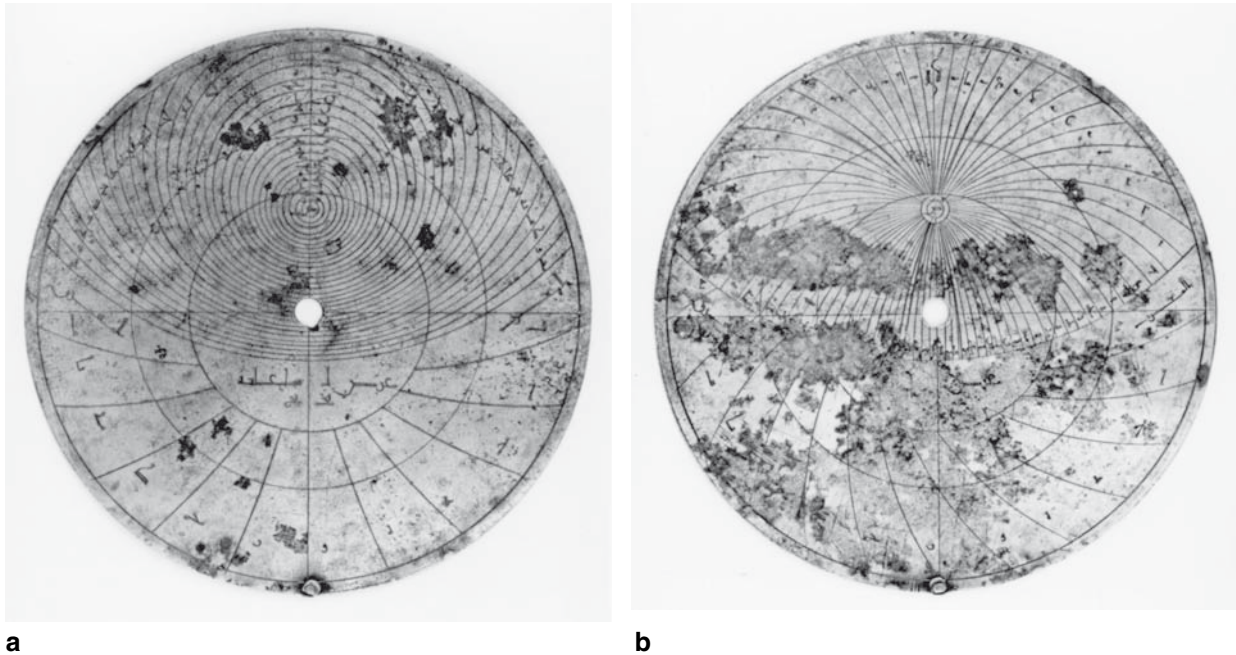
latitudinal bands whose limits and mid-points are defined in terms of the longest daylight), the idea being to render the instruments universal. The first geographical tables on astrolabes gave only the latitudes of a series of localities, their purpose being to indicate which plate one should use. (Medieval texts often advocate interpolating between the results derived from two plates with a lower and higher latitude than one's own.) Later astrolabe plates were engraved for a series of latitudes no longer corresponding to the seven climates (although these often lurk in the background in a disguised form). Often the length of longest daylight at those latitudes would be included, this being another feature reminding the user of the notion of the climates. (An indication of the traditionalism that prevailed amongst astrolabists is that Ptolemy's value of the obliquity was used for these lengths for centuries after updated values of the obliquity had been derived by new observations.) Sometimes a list of localities served by each of the plates would be included.

The plates of an astrolabe often yield clues as to the provenance of the instrument. Usually the plate for the latitude of the locality where the instrument was made has additional markings. Thus, for example, an astrolabe preserved in Copenhagen has special markings on the plates for latitudes 34° and 40° which serve to find the direction of Mecca at Herat and Samarqand, respectively. Since it was made in 1428 for the treasury of a prince whose name has been obliterated, we are clearly dealing with an astrolabe made in Samarqand for the Timurid astronomer-prince Ulugh Beg himself, for his duties caused him to oscillate between these two cities: see **Figs. XIVd-1**. Alternatively, the latitudes used on astrolabe-plates provide information on the scientific milieu in which the instruments were constructed. Thus, for example, some 11th-century Andalusi astrolabes give 33;9° as the latitude of Baghdad: this is a clear indication of the influence in al-Andalus of the astronomical tables of the earlier astronomers al-Khwārizmī and al-Battānī from the Islamic East, both of whom used this (inaccurate) value. Likewise, the inclusion of a plate for latitude 39;52°, which is Ulugh Beg's value for Samarqand, in the earliest astrolabes of the Lahore school (**XIVf-3**) is a clear indication of the source of the inspiration for the activity of the school.

On the geographical information that can be derived from early instruments see King, "The Geography of Astrolabes", now in **XVI**. New information on Indian coordinates is to be found in Sarma, "Sulṭān, Sūri and the Astrolabe". For investigating specific latitudes attested on instruments it is important to know which localities were thought to have these latitudes in the Middle Ages rather than which localities actually have these latitudes. For this Kennedy & Kennedy, *Islamic Geographical Coordinates*, based on about 75 sources, is invaluable. On the lengths of daylight for specific latitudes, see King, *Mecca-Centred World-Maps*, pp. 75-76. See also the notes on qibla-indicators in **Ch. 8** below.

4.5 Special markings relating to prayer

Some of the markings introduced by Muslim astronomers on the standard astrolabe have to do with Muslim prayer. It is the duty of every Muslim to perform five prayers each day at times that are astronomically defined (**II**). These prayers begin when the sun has disappeared over the horizon at sunset, at nightfall, at daybreak, either at astronomical midday or shortly

a b

Figs. 4.4.1a-b: The front and back of a solitary plate (#4150) that is unique of its genre. I strongly suspect that it was by the early-15th-century astrolabist Jalāl al-Kirmānī, and I should have included it in **XIVd**. The markings on both sides are for latitude 30°, usually suggesting Cairo, but in this case, they may be for Kirman. On the front we find altitude circles for each 3° of argument and markings for the seasonal hours. On the back we find altitude circles for each 5° of argument and markings for the hours since sunset. The knobs at the bottom look at first sight like an absurd later addition; however, they may be original, in which case they are most unusual and it is not at all clear how they would have functioned. [Object now in the Nasser D. Khalili Collection in London; photos courtesy of Sotheby's of London.]

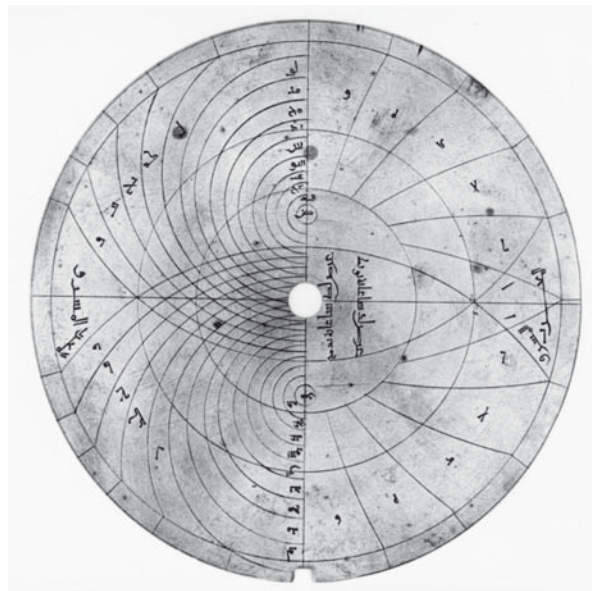



Fig. 4.4.2: An unusual plate in an astrolabe made by Muḥammad ibn Ḥāmid ibn Maḥmūd al-Iṣfahānī in 556 H [= 1161] (#1177). The lower markings serve latitude 34° and the upper ones latitude 39°. Around the centre of the plate, the two sets of markings are superposed. [Courtesy of the Türk ve Islâm Eserleri Müzesi, Istanbul.]

thereafter, and at mid-afternoon. The beginnings of the permitted intervals for the daylight prayers are defined in terms of shadow lengths, and the corresponding times for the night prayers are defined in terms of sunset and twilight phenomena. Most astrolabic plates for specific latitudes show special markings for the prayers at mid-afternoon, nightfall and daybreak, and the times of midday and sunset are easily determined with an astrolabe anyway. See **Fig. 4.5.1** and **IV-7.3** and also **Fig. 6.4.3** on a quadrant with unusual astrolabic markings for times of the day with religious significance.

Also it is the duty of every Muslim to face Mecca during prayer, and it is thus required to know the direction of Mecca from any locality. At least for the scientists, this involved calculating the direction from the latitudes and the longitude difference (**VIIa**). By medieval standards, the formula for finding the qibla is complicated in the extreme; however, correct formulae were derived already in the 9th century. Especially in the Eastern Islamic world, astrolabists after about the 13th century engraved lists of localities together with their latitudes, longitudes, and qiblas on the maters of their astrolabes, or palettes of qibla directions in a quarter-circle: see **Fig. XIIIa-6.1b**. After the 16th century the latter were replaced by graphs displaying a family of curves representing the altitude of the sun throughout the year when the sun is in the direction of Mecca in various places: see **Fig. 4.5.3**.

None of these specifically Islamic aspects of astronomy in general, or of instrumentation in particular, had any influence in medieval Europe beyond Spain, for obvious reasons.

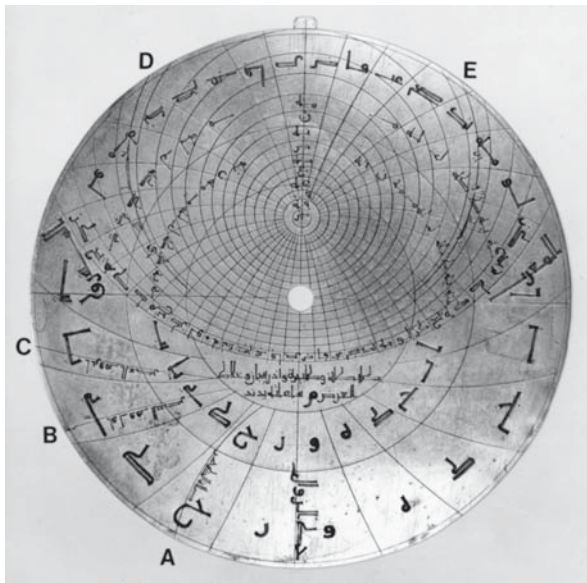
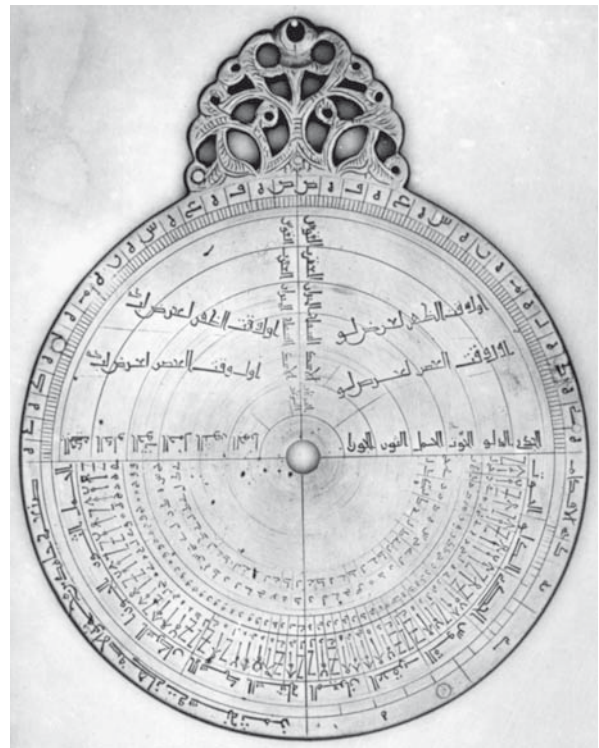
On certain kinds of markings for the prayers see Viladrich, “Prayer Curves on Iranian Astrolabes”, and Charette, *Mamluk Instrumentation*, pp. 170-179. On the markings for the qibla on the backs and

→

Fig. 4.5.1: A plate from an 11th-century Andalusī astrolabe (#118) displaying curves for the *ẓuhr* (A: shadow increase over midday minimum equal to one-quarter of the length of the gnomon), the beginning of the *ʿaṣr* (B: shadow increase equal to the length of the gnomon), and the end of the *ʿaṣr* (C: shadow increase equal to twice the length of the gnomon), amidst curves for each seasonal hour of daylight from 1 to 12. Since the times of the prayers are here defined by means of shadow increases, they therefore no longer correspond to their original definitions in terms of the seasonal hours. There are also markings at 18° above the horizon for the night-time prayers (D: nightfall, for the *ʿishāʾ*, and E: daybreak, for the *fajr*). The plate serves latitude 40°, and Toledo, Talavera, Azerbeijan and Akhlat are specifically mentioned. [Courtesy of the Museum of the History of Science, Oxford.]

Fig. 4.5.2: The back of an astrolabe made by Ḥāmid ibn Maḥmūd al-Iṣfahānī in 547 H [= 1152/53] (#4) with the upper two quadrants showing the solar altitude at the beginning of the *ẓuhr* and *ʿaṣr* prayers as functions of the solar altitude. The markings on the left serve 32;25°, which is for Isfahan, and those on the right are for latitude 36°, which could serve Rayy or simply the middle of the 4th climate. Below the horizontal diameter are astrological markings, and the juxtaposition of these with markings for the prayers is not without interest. [Object in the collection of Leonard Linton, photo from the archives of the late Alain Brieux, courtesy of Dominique Brieux.]

Fig. 4.5.3: The markings on this quadrant on the back of this Safavid astrolabe (#18), made in Isfahan in 1057 H [= 1647/48] by Muḥammad Muqīm al-Yazdī for Shāh ʿAbbās II, display the altitude of the sun in the qibla of various localities for all solar longitudes. It is not known who first conceived of preparing graphical representations of this particular function, but solar scales of this kind for other functions had been introduced in the 10th century. [Courtesy of the Museum of the History of Science, Oxford.]

Fig. 4.5.4: Markings indicating the direction of Mecca and Kerbela from an unspecified locality on the back of a late Iranian astrolabic plate (#4203). The markings on the front (see Fig. 4.1.6) are for latitude 36°, which enables us, using medieval coordinates, to identify the locality in question as Hamadan. [Courtesy of the National Maritime Museum, Greenwich.]

4.5.1

4.5.2

4.5.3

4.5.4

Fig. 4.5.5: Baghdad and Kufa amongst the stars on an astrolabe rete made by the Shīʿī astrolabist ʿAbd al-Aʾimma in Isfahan *ca*. 1700 (#4225). Behind the fantasy was an unshakable belief in the sanctity of those cities. [Photo courtesy of Christie's of London.]

occasionally on the plates of Iranian astrolabes, see King, *Mecca-Centred World-Maps*, pp. 104-108 and 186-193.

4.6 Astrological markings

Already the astrolabe of al-Khujandī has two kinds of markings for astrological purposes. Firstly, there are plates for performing the astrological operation known as "casting the rays". Secondly, there are astrological tables engraved on the back showing the "terms" of the zodiacal signs, the "lords of the faces", and the planets associated with triplicities (**Figs. XIIIc-9b**, also **X-4.7.3**). Similar tables are found on the back of the astrolabe of al-Ashraf, and these correspond to those illustrated in his treatise on astrolabe construction (**Figs. XIVa-2.2** and **3.1**). **Fig. 4.6.1** shows these latter markings on the back of a monumental astrolabe from early-13th-century Damascus.

On the astrological data on the backs of certain Islamic astrolabes see Hartner, "Astrolabe", A, pp. 304-307; King, "Kuwait Astrolabes", pp. 87 and 89, now in **XIIIc-9**, and *idem*, "Yemeni Astrolabe", pp. 106-107, now in **XIVa-2**, On the astrological plates found in certain astrolabes in and after the 10th century see Mercè Viladrich & Martí, "El *Libro dell Ataçir*", and also North, *Horoscopes and History*, pp. 1-69. See also Calvo, "La résolution graphique des questions astrologiques".

Fig. 4.6.1: Astrological markings on the back of the Oxford astrolabe (#103) of ʿAbd al-Karīm al-Miṣrī, made in Damascus in 625 H [= 1227/28]. This kind of information was also available in astrological handbooks. With an astrolabe one can determine the basis of a horoscope, that is, determine the ascendant and the longitudes of the astrological houses. But then one needs an ephemeris (*taqwīm*) to find the positions of the sun, moon and five planets, insert them in the appropriate houses, and establish their (supposed) mutual influences. The markings on the London astrolabe (#104) by the same maker have been studied in detail in Hartner, "Astrolabe", A, pp. 2547-2550 (pp. 304-307 of the reprint). [Taken from Gunther, *Astrolabes*, pl. LIV; object in the Museum of the History of Science, Oxford.]

4.7 Additional markings

A set of scales for finding the solar longitude from the date in any one of the solar calendars (Syrian, Iranian, Coptic or "Western") is a feature on the backs of certain Eastern astrolabes and virtually all Western Islamic instruments. It seems fairly certain that this is an Andalusī contribution. The question remains whether it was originally part of a hypothetical Roman tradition that became known in Spain before it even entered Muslim circles (see **XIIIa-9**). In any case, the medium for transmission to the Islamic East is perhaps the treatise on the astrolabe by the Andalusī Abu 'l-Ṣalt *ca*. 1000, compiled whilst he was in prison in Egypt. In this (MS London Or. 5479,1, *naskhī*, Egypt *ca*. 1200, fols. 4v-6r), he presents both a table of the solar longitude to the nearest degree for each day of the Syrian year, and then advocates the construction on solar and calendrical scales for the Syrian or the Coptic year on the back of the astrolabe. This is the earliest mention of such a procedure known to me. It is significant that he does not mention the Western Andalusī calendar, and also that his treatise was influential in the Islamic East (see **XIIIe** *addendum*).

Sometimes, extensive calendrical scales were included on Western Islamic instruments: see **Fig. 4.7.2**. Also astrological information was occasionally engraved on the mater or back: see **4.6** and **Fig. 4.7.3**. The other markings introduced by Muslim astrolabists on the backs of astrolabes were shadow scales and trigonometric and/or horary quadrants: see again **Fig. 4.7.3**. The latter are best considered separately—see **6**.

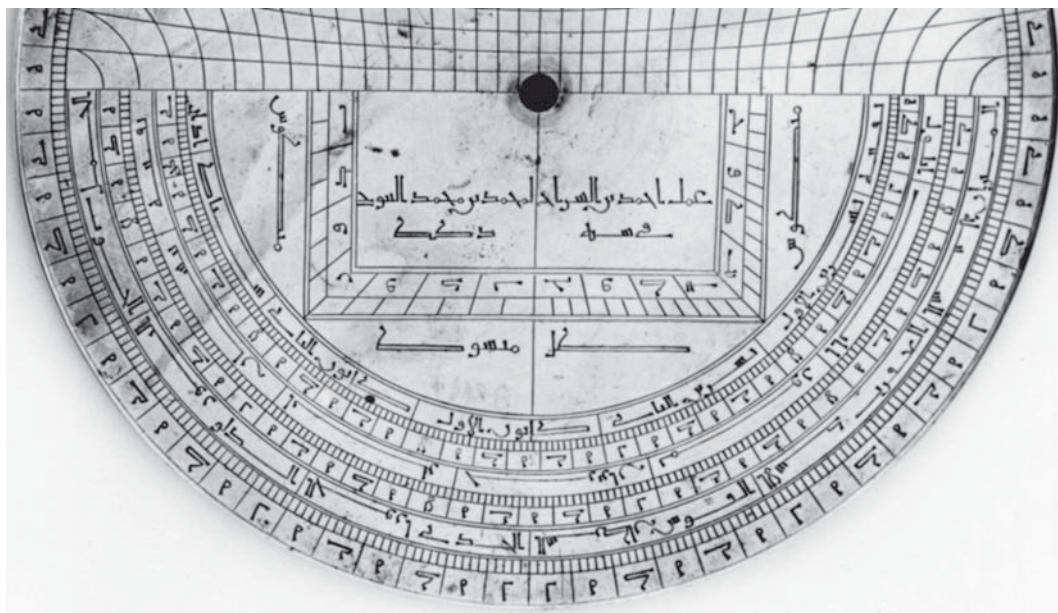



Fig. 4.7.1: Scales displaying the solar longitude as a function of the date in one of the solar calendars are rare on Eastern Islamic instruments, but common on Western Islamic and medieval European instruments. At least on the Islamic instruments, these scales are accurately constructed and can be used to date the instrument in question, although Islamic instruments are usually dated. Here, on the spectacular astrolabe of Ibn al-Sarrāj (#140), the scales are concentric and serve the Syrian calendar. The equinox is at Ādhār 10, which corresponds to the 17th century, whereas the astrolabe was made in 729 H [= 1328/29]. It is not clear what is going on here: see further **XIVb-5.1**. With medieval European instruments there is a severe problem, since the scales are often for an epoch other than the date of construction of the instruments, which are not dated. [Courtesy of the Benaki Museum, Athens.]

On calendrical scales, albeit on European instruments see, most recently, G. Turner, “Dating Astrolabes”. On shadow-scales see now **XIIa-A**.

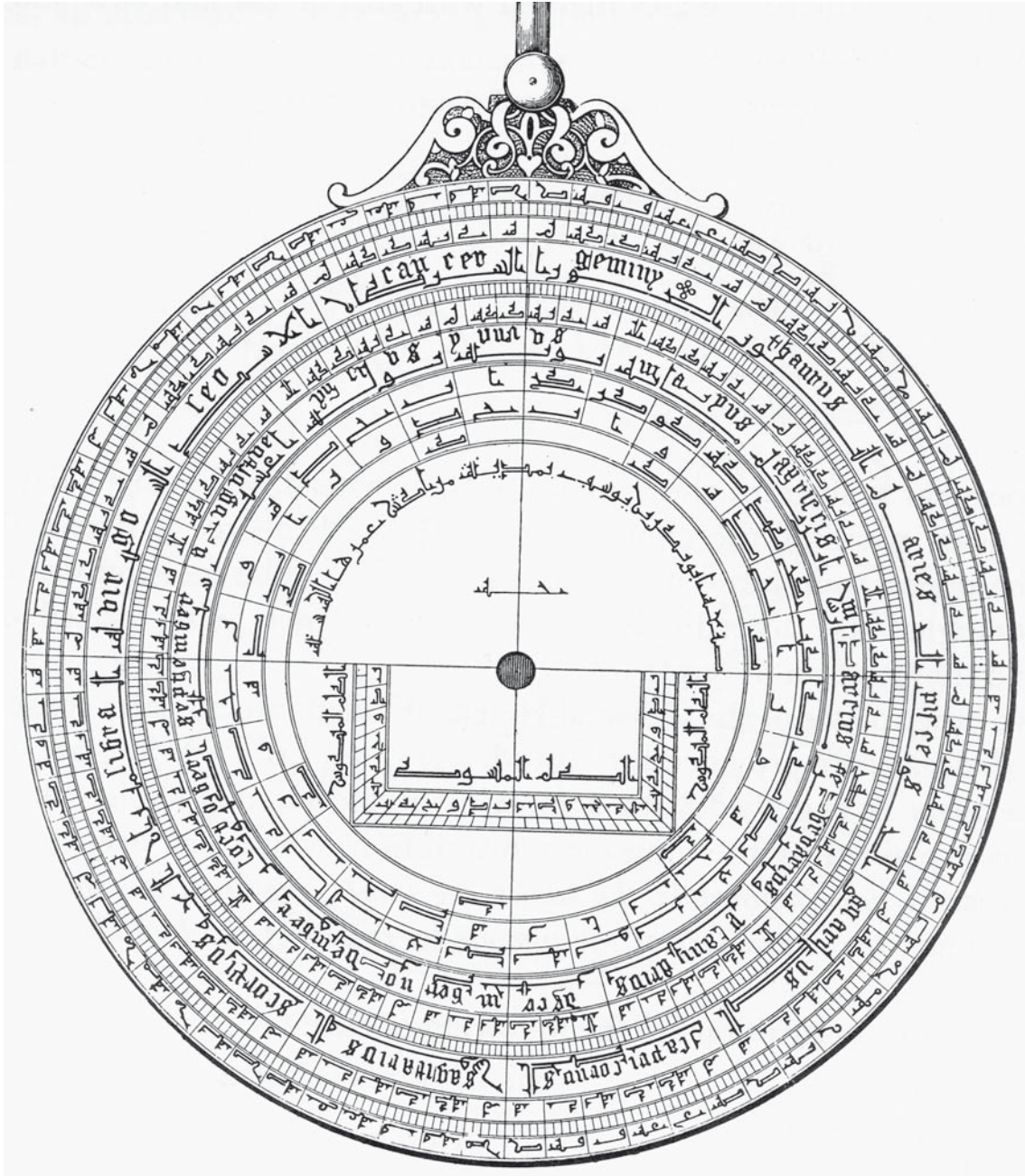



Fig. 4.7.2: On the back of this astrolabe by Abū Bakr ibn Yūsuf, made in Marrakesh in 605 H [= 1208/09] (#124), we find more than the standard solar and calendrical scales. Inside the latter, there is a kind of perpetual calendar, enabling the user to find the day of the week from the date within a 28-year solar cycle: see also **Fig. XIIIa-10.2b**. The new description by Francis Debauvais and Paul André Befort in *Strasbourg Astrolabe Catalogue* includes details of the Latin additions not visible on Sarrus’ original illustration. [From Sarrus, “Astrolabe marocain”.]

Fig. 4.7.3 The back of the astrolabe made by Badr, *mawlā* of Hibatallāh al-Aṣṭurlābī, in 525 H [= 1130/31] (#2557) is also in the tradition of al-Khujandī (see **Fig. 4.1.1** for the front). Above the horizontal diameter is a quadrant of trigonometric markings and an horary quadrant for latitude 36°, which is probably intended to serve Rayy, but maybe simply for the middle of the 4th climate. Below we find the same kind of astrological information as on the astrolabes of al-Khujandī (see **Fig. XIIIc-9.2**) and ʿAbd al-Karīm al-Miṣrī (**Fig. 4.6.1**). [Courtesy of the Adler Planetarium, Chicago.]

CHAPTER 5

NON-STANDARD ASTROLABES

5.1 Non-standard retes

The northern and southern halves of the ecliptic project into dissimilar arcs of the ecliptic on the rete of the standard astrolabe. This fact motivated several astronomers in the 9th and 10th centuries to devise highly ingenious retes on which the two halves of the ecliptic were represented symmetrically. Such astrolabes required special kinds of plates, and the compilation of treatises on their use called for considerable ingenuity on the part of their inventors—see **Fig. 5.1.1**. Most of these different instruments were probably constructed in no more than a few examples, and only one such astrolabe is known to have survived, a 'myrtle' astrolabe made by ʿAlī ibn Ibrāhīm al-Jazzār in Taza (now in Morocco) in the year 728 H [= 1327/28] and now preserved in Oxford. In this, the northern and southern parts of the ecliptic are now similar (**Fig. XIIId-6**), but we are here dealing with a Western Islamic innovation rather than an Eastern Islamic one. A single plate from an Eastern Islamic astrolabe of the 10th or 11th century with 'ogival' markings is preserved for us (**Fig. XIIIc-10a**) as well as a 13th-century astrolabic plate from Syria (**Fig. XIVb-3**). A small Italian astrolabe from *ca*. 1300 derives from an Islamic tradition of providing a myrtle-shaped ecliptic together with a set of plates for the seven climates (**Figs. XIIId**). A 14th-century geared astrolabe from N. France has a rete and plate for a northern projection (**Fig. 5.4.3**), such as were made in the Islamic East in the 9th and 10th centuries, if not often thereafter (no Islamic examples survive).

Of considerable historical interest is a non-standard astrolabe devised by Ḥabash al-Ḥāsib in the mid 9th century and known to us only from manuscripts. This is the so-called 'melon' astrolabe, in which the meridians on the sphere are projected into radii through the south pole in the tangential plane (**Fig. 5.1.2**). The ecliptic and the altitude circles are no longer circular, hence the name of the astrolabe. The astrolabic projection described by the 10th-century scientist al-Ṣaghānī of Baghdad is also of great mathematical interest: it yields an ecliptic in the form of an ellipse and altitude circles that are a variety of conic sections.

Another early variety of astrolabe in which the astrolabic markings for a specific latitude and the projection of the ecliptic and stars are all on a single astrolabic plate is known from textual sources and two examples, of which one is shown in **Fig. 5.1.3**.

On the development of different varieties of astrolabe retes see Frank, *Zur Geschichte des Astrolabs*. Richard Lorch has prepared for publication a study of al-Sijzī and al-Bīrūnī on non-standard astrolabe retes. See already Lorch, "Mischastrolabien", and also *idem*, "Al-Ṣaghānī on Projecting the Sphere". On the melon astrolabe see now Kennedy & Kunitzsch & Lorch, *Melon Astrolabe*, also Charette, *Mamluk Instrumentation*, pp. 81-83.

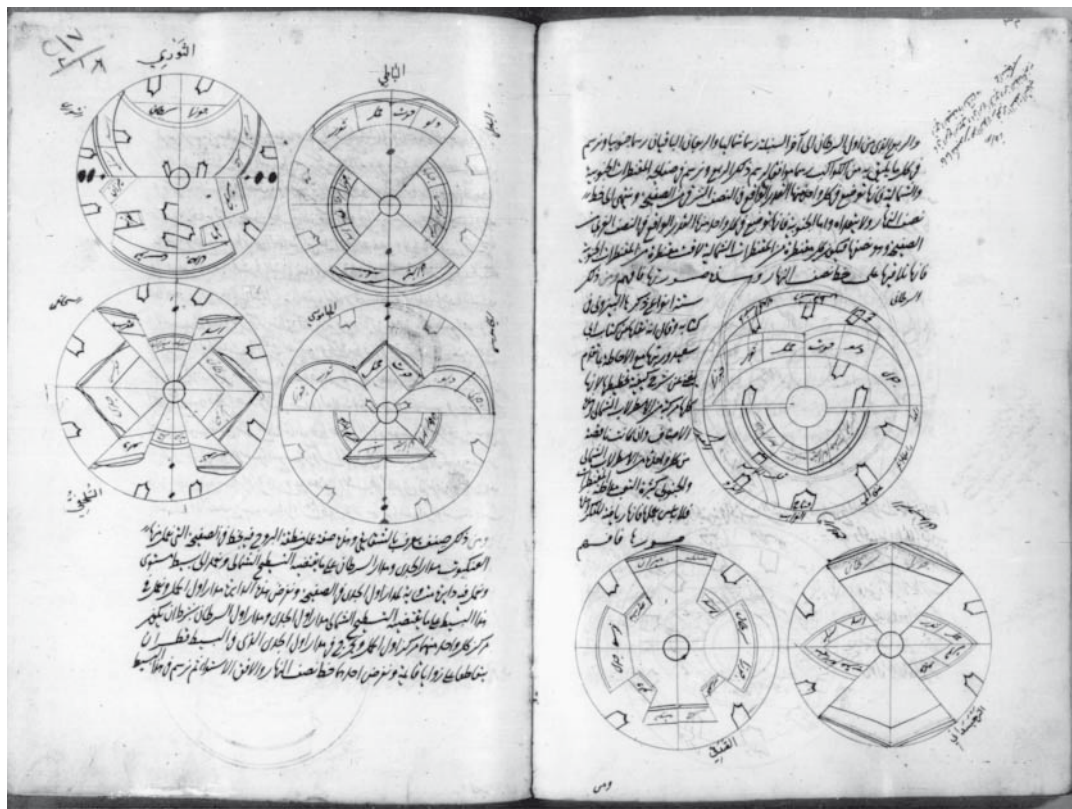



Fig. 5.1.1: Some non-standard astrolabe retes illustrated in the A-Z on spherical astronomy and instruments by the 13th-century Cairo-based astronomer of Moroccan origin Abū ʿAlī al-Marrākushī. It was supposed until recently that such astrolabes were probably never actually made, but now we have the treatise of al-Sijzī (*fl.* 975) describing the various types and mentioning the names of those who invented them and to whom examples were presented. It is now clear that aspects of this tradition passed to Europe, but the details of transmission are obscure indeed. [From MS Cairo Dār al-Kutub K 3821, fols. 216v-217r, courtesy of the Egyptian National Library.]

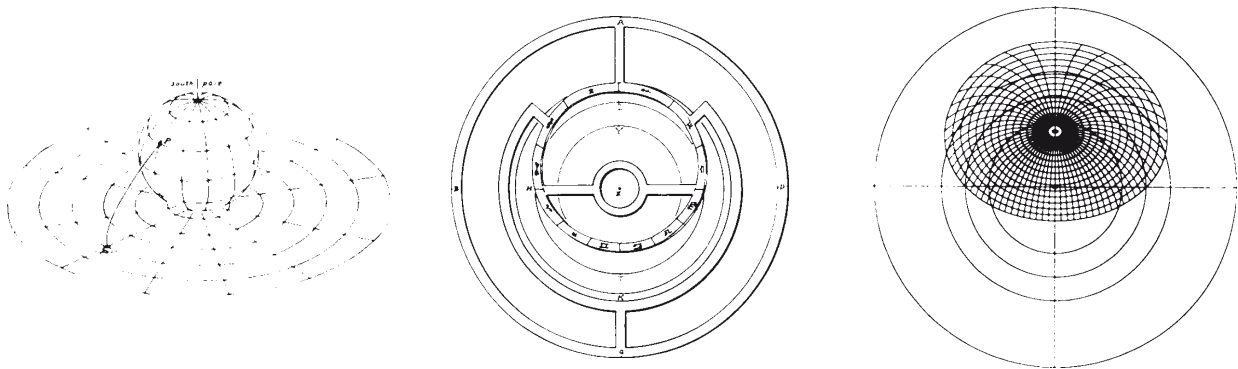



Fig. 5.1.2: The projection underlying the construction of the "melon" astrolabe, as well as a reconstruction of the rete and a plate. In the Middle Ages, such an astrolabe would have simply been thrown out as incompetently made. Nowadays, it would be dubbed a fake by would-be experts. [From Kennedy & Kunitzsch & Lorch, *Melon Astrolabe*, pp. 3, 69 and 144, with permission of the authors.]

Fig. 5.1.3: A “solid” (*mujammad*) astrolabe made by ʿUmar ibn Dawlatshāh al-Kirmānī in 726 H [= 1325/26] (#4033). The “rete” is already engraved over the makings for a specific latitude, in this case, 36°, and the radial rule with a declination scale is missing. Note that the ecliptic scale around the rim is appropriately divided according to the right ascensions. [Object in the collection of Leonard Linton, photo from the archives of the late Alain Brieux, courtesy of Dominique Brieux.]

5.2 The universal plate and universal astrolabe

In Baghdad in the mid 9th century, Ḥabash devised a plate with markings representing the horizons of various localities. He noticed that the problems relating to risings, culminations and settings of celestial bodies could be solved for all latitudes using such a plate and a rete displaying the ecliptic and fixed stars. This notion was developed further in Toledo in the 11th century. Muslim astronomers there developed a universal plate from the markings on an astrolabic plate for latitude zero and thence an astrolabe that would function for all latitudes with a single plate.

The astronomer Ibn al-Zarqālluh (d. *ca*. 1100), known in the West as Azarquiel, appears to have developed the universal plate called al-*shakkāziyya* with a regular alidade, with which

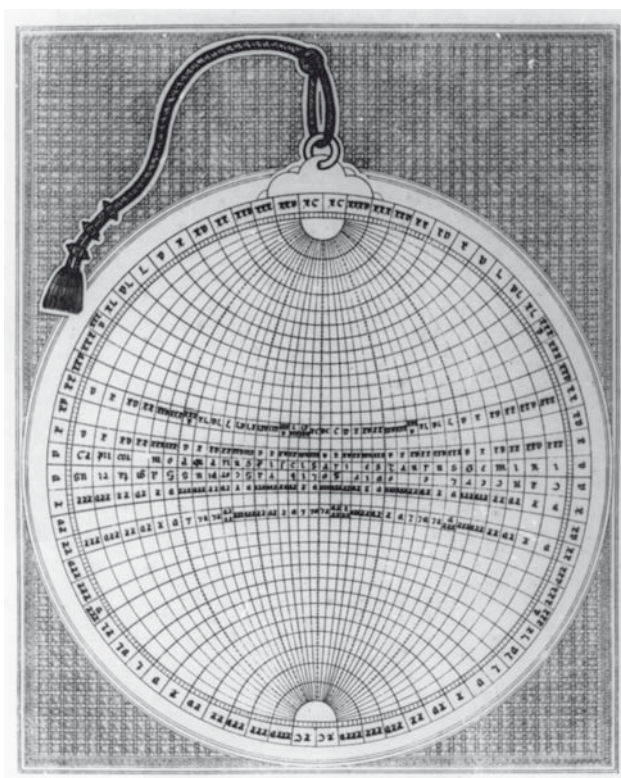



Fig. 5.2.1: A *shakkāziyya* plate as illustrated in the 13th-century *Libros del saber de l'astronomía*. The grid was labelled *shakkāziyya* by its inventor, Ibn al-Zarqālluh, and the origin of its name is obscure. [From the printed edition.]

some of the problems of spherical astronomy can be solved only approximately. He also devised the plate called al-*zarqālliyya* which consisted of two *shakkāziyya* grids inclined at an angle equal to the obliquity; the alidade is now equipped with a movable cursor and the combination serves only to convert between ecliptic and equatorial coordinates. See **Figs. 5.2.1-2**.

The *shakkāziyya* plate is found on a minority of European astrolabes from the 14th century onwards. In medieval Europe it was called "*saphea*", from the Arabic *ṣafīḥa*, "plate". See **Fig. 5.2.3** for a Renaissance example from 16th-century Louvain.

The astronomer ʿAlī ibn Khalaf al-Shajjār, a contemporary of Ibn al-Zarqālluh, developed a more sophisticated and more useful instrument. Taking the basic notions—that the *shakkāziyya* plate could be used to represent in two dimensions any orthogonal spherical coordinate system, and that two such plates superposed one upon the other could be employed to solve any problem of coordinate transformation, which problems are the essence of spherical astronomy—to their natural conclusion, he invented the universal astrolabe. His instrument is known only from the 13th-century Andalusi compilation entitled *Libros del saber de astronomía*: the rete consists of one semicircle of *shakkāziyya* markings and another comprising an ecliptic and star-pointers with northern and southern halves of the ecliptic superposed one upon the other, and the plate is a *shakkāziyya* grid. Only one such astrolabe survives, curiously enough

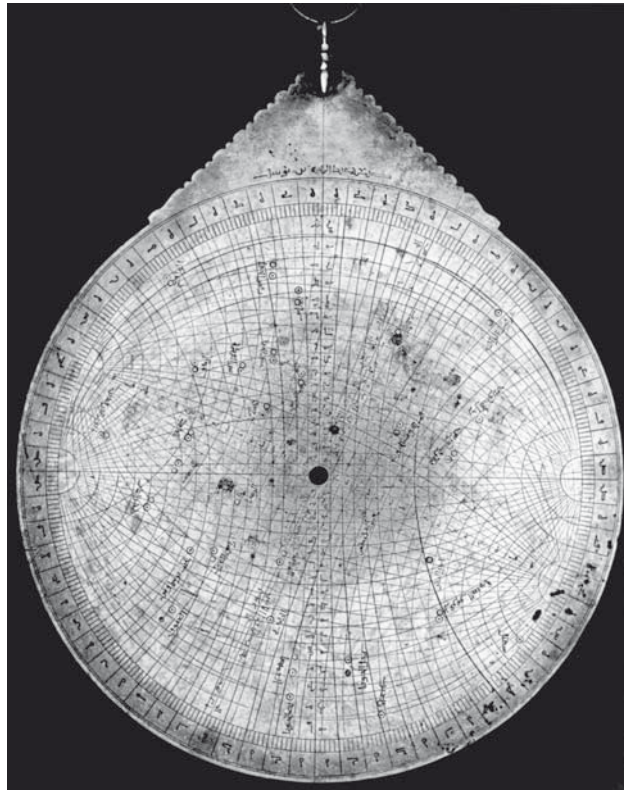



Fig. 5.2.2: A *zarqālliyya* made in Damascus by ʿAbdallāh ibn Yūsuf in 695 H [= 1295/96] (#102). The same maker also signed another instrument of this kind two years earlier, but is otherwise unknown to us. The grid consists of two sets of *shakkāziyya* markings inclined at an angle equal to the obliquity of the ecliptic. [Courtesy of the Victoria and Albert Museum, London.]

from 17th-century India: the rete was auctioned at Christie's of London in 1995 and the mater was identified at an art dealer's in Germany in 2000 (see now **XIVg**). The design of the rete indicates that it was copied, not necessarily directly, from a rete by Ibn al-Sarrāj (see below).

The universal astrolabe of ʿAlī ibn Khalaf and his treatise on its use do not seem to have been known in the Muslim world outside al-Andalus. The same instrument was 'reinvented' in the early 14th century by Ibn al-Sarrāj in Aleppo, and a unique example designed and constructed by him survives in the Benaki Museum in Athens—see **Fig. 5.2.4**. In his treatise on a simplified version of the instrument he claims to have invented it himself, and this there is no reason to doubt. But the surviving astrolabe of Ibn al-Sarrāj is far more complicated and sophisticated than that of ʿAlī ibn Khalaf or the same instrument described in Ibn al-Sarrāj's treatise: it contains a set of quarter-plates for all latitudes, a plate of horizons for all latitudes, and other features such as a universal trigonometric grid; indeed, the instrument can be used universally in five different ways. It is without doubt the most sophisticated astronomical instrument from the entire medieval and Renaissance periods: see further **XIVb-5.1**.

The universal astrolabe of ʿAlī ibn Khalaf was 'reinvented' once again in England in the late 16th century, this time by John Blagrave. He was not aware of the more complex and more

Fig. 5.2.3: A device for converting spherical coordinates from any system into any other. The problems of spherical astronomy involve such conversions between the ecliptic, equatorial and horizon-based systems. It was Ibn al-Zarqālluh who advocated the use of an alidade with a movable transversal cursor—here developed further into a *brachiolus*—to facilitate operations. This particular *shakkāziyya* occurs on an astrolabe by Arsenius (Flanders, 16th century), and although no instruments by Ibn al-Zarqālluh survive, instruments made with this kind of precision were being made by Muslim astronomers in the 13th century. [Courtesy of the Science Museum, London.]

versatile instrument of Ibn al-Sarrāj, and it is doubtful whether he would have known what to do with it even if he had been.

In the early 14th century the theologian, mathematician and astronomer Abū ʿAlī al-Ḥasan ibn Muḥammad ibn Bāṣo of Granada devised a brilliant modification of the *shakkāziyya* grid for use with a standard astrolabe rete. On this each one of three sets of circular markings is associated with a specific astronomical argument (declination, altitude, *etc.*) depending on the problem to be solved. Each of the *zarqālliyya* and *shakkāziyya* plates and the plate of Ibn Bāṣo were also known in the Muslim East.

On the universal astrolabe and plate see King, "Universal Astrolabe", and my article "*Shakkāziyya*" in EI_2, and the earlier studies of J. Millás Vallicrosa including: "Azarquiel sobre la azafea"; *Don Profeit Tibbon sobre l'assafea*; *Azarquiel*; and "Azafea árabe". Important new studies are Puig, *Al-Šakkāzīya*;

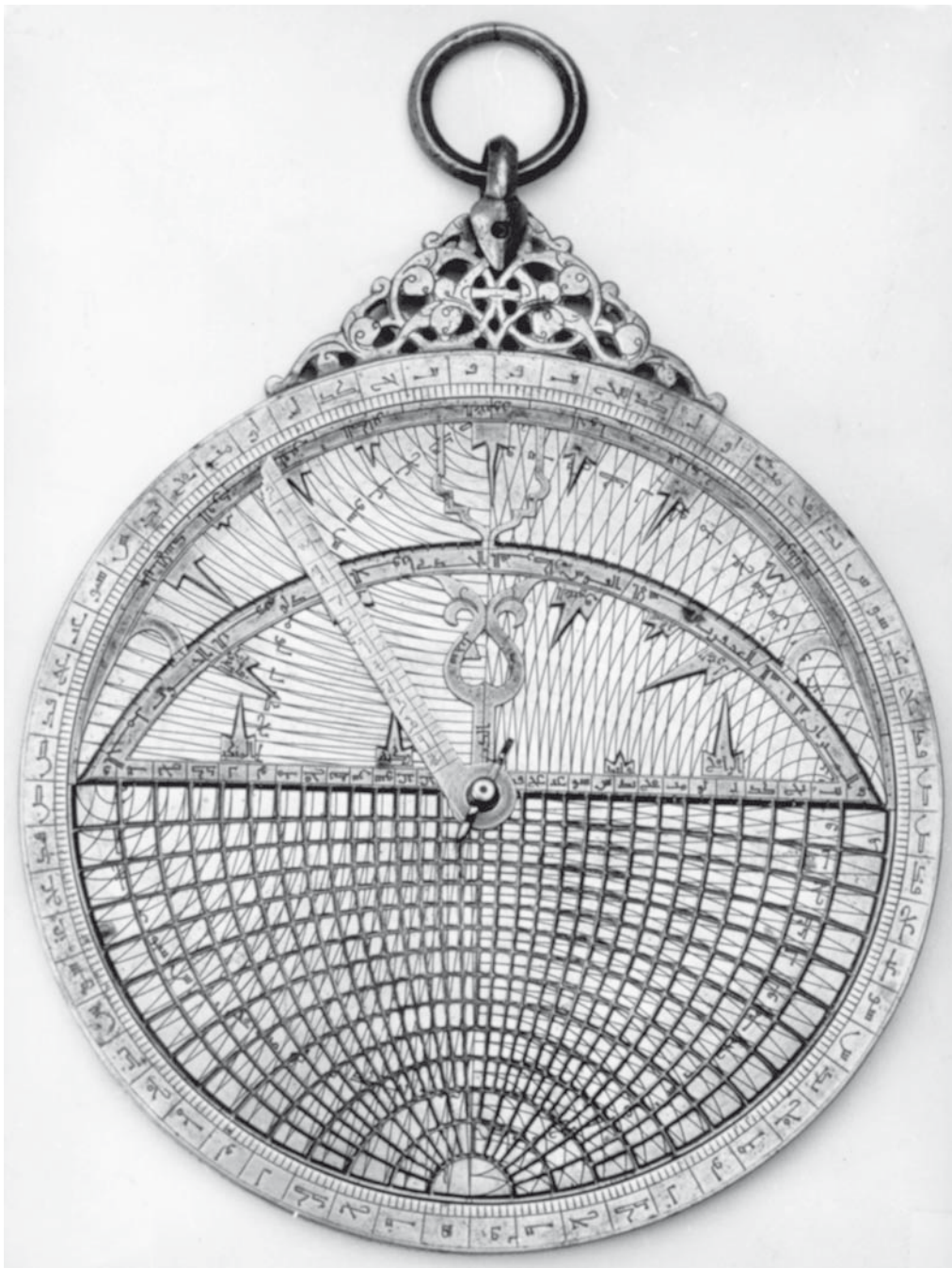



Fig. 5.2.4: The most sophisticated astrolabe ever made. The universal astrolabe of Ibn al-Sarrāj, made in 729 H [= 1328/9] in Aleppo (#140), merits such a description: it can be used universally in five different ways. The first universal astrolabe was invented by ʿAlī ibn Khalaf in al-Andalus in the late 11th century and (like the virtually identical "Mathematical Jewel" of John Blagrave of Reading in the 16th century—see **Fig. 5.2.5**) was capable of being used universally in two different ways. However, Ibn al-Sarrāj seems to have reinvented the instrument, and he certainly developed it further. But the use of this particular astrolabe in all of its potential would have been beyond most astronomers in the Islamic world, and indeed beyond most in Renaissance Europe. [Courtesy of the Benaki Museum, Athens.]

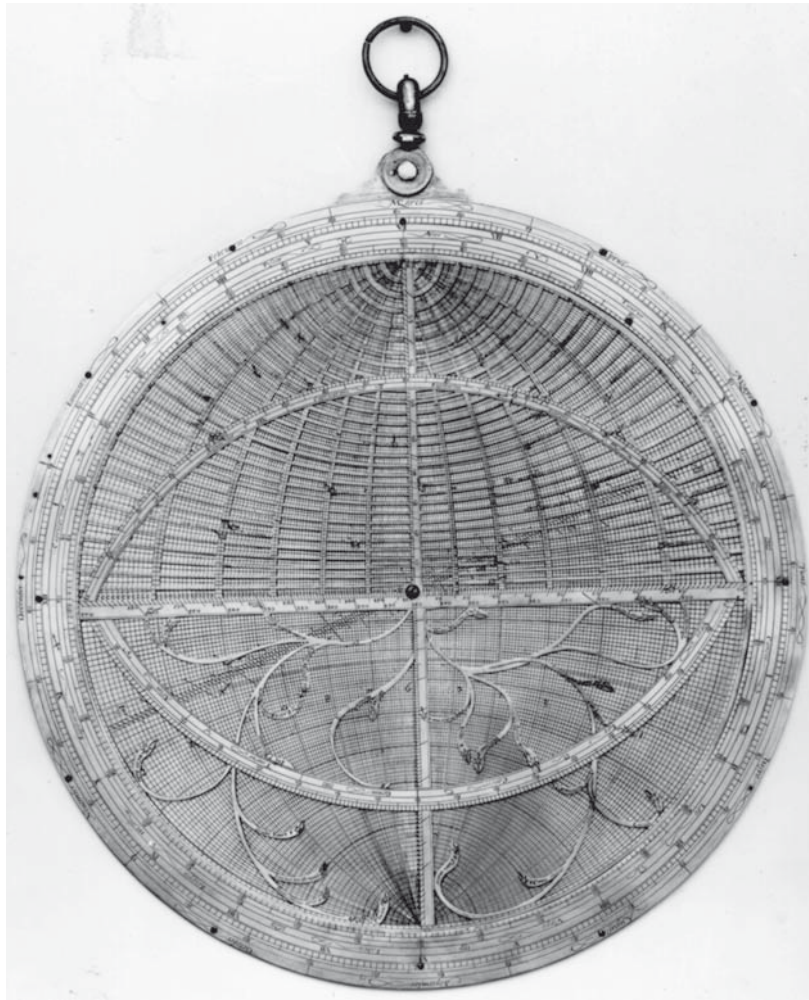



Fig. 5.2.5: One of the finest instruments of Elizabethan England: a universal astrolabe of the kind known as "mathematical jewel" designed by John Blagrave, made by Charles Whitwell in 1595 (#482). There are 700 years of development behind Blagrave's instrument. The full myrtle ecliptic was designed in Baghdad in the 9th century. The simple universal astrolabe was designed in al-Andalus in the 11th century. A calendrical scale was proposed for the front of the simple universal astrolabe in a treatise by Ibn al-Sarrāj, Aleppo, early 14th century. The medieval European tradition of the universal astrolabe is obscure. Perhaps Blagrave did develop it independently, but this seems unlikely. This piece was taken to Florence by Sir Robert Dudley in 1606. See further G. Turner, *Elizabethan Instruments*, pp. 187-190 (no. 43). On Blagrave's treatise, see Gunther, *Astrolabes*, II, pp. 492-500 (no. 308). [Courtesy of the Museo di Storia della Scienza, Florence.]

eadem, "*Ṣafīḥa shakkāzīya*"; *eadem*, *Azafea de Azarquiel*, and *eadem*, "Instrumentos universales en al-Andalus". On the orthogonal-type markings on the back of the *zarqālliyya* see *eadem*, "Ibn al-Zarqālluh's Orthographic Projection"; and on the highly ingenious 'circle of the moon' see *eadem*, "Al-Zarqālluh's Graphical Method". There is a dire need for the first serious study of the universal astrolabe: this is now being undertaken by Professors Roser Puig and Emilia Calvo in Barcelona.

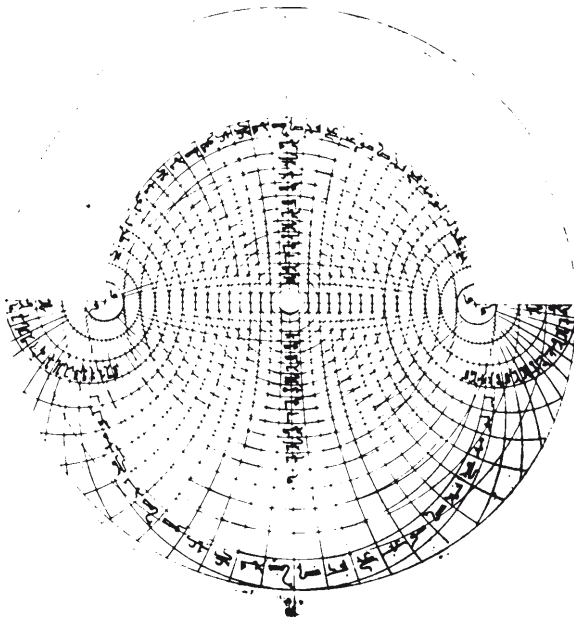



Fig. 5.2.6: The universal plate of Ibn Bāṣo, as found on one of a set of plates inside an astrolabe (#1203) made by his son, Aḥmad ibn Ḥusayn ibn Bāṣo in 709 H [= 1309/10]. [Private collection, photo courtesy of the owner.]

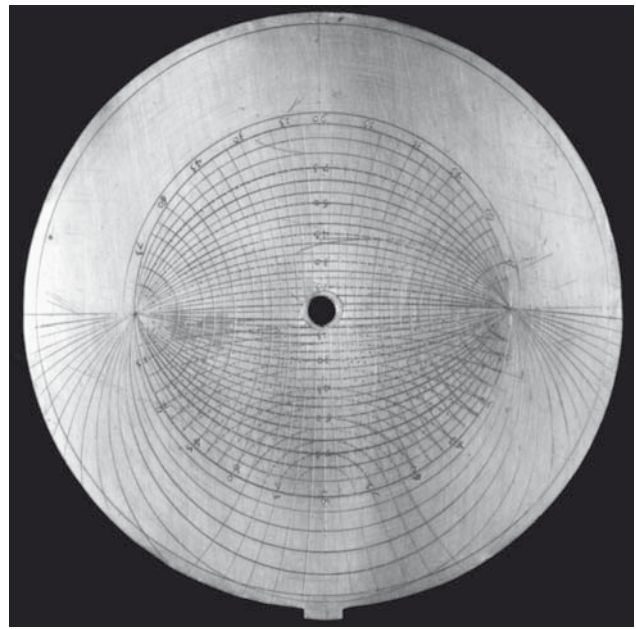



Fig. 5.2.7: A similar universal plate on an astrolabe from either Vienna or Nuremberg (#545). The relationship of this to the plate of Ibn Bāṣo has yet to be investigated. [Courtesy of Special Collections, Columbia University, New York.]

On Ibn Bāṣo and his universal plate see Calvo, *Ibn Bāṣo and his Universal Plate*; *eadem*, "Ibn Bāṣo's Universal Plate"; and *eadem*, "The Use of Ibn Bāṣo's Universal Plate". On another ingenious trigonometric device, see *eadem*, "Ibn Bāṣo's *Ṣafīḥa mujayyaba*".

On a 13th-century Mamluk universal instrument see King, "The Astrolabe of ʿAlī al-Wadāʿī", in *idem*, *Studies*, B-VIII, now in **XIVb-3**. On the 14th-century Benaki astrolabe of Ibn al-Sarrāj see King, "The Astronomical Instruments of Ibn al-Sarrāj", in King, *Studies*, B-IX, and now **XIVa-5.1**, but more especially Charette & King, *The Universal Astrolabe of Ibn al-Sarrāj* (forthcoming).

On an Indian universal astrolabe based on another, less complicated universal astrolabe of Ibn al-Sarrāj, see *Christie's London 04.10.1995 Catalogue*, pp. 20-21, lot 61 (rete), and *05.04.2001 Catalogue*, pp. 43-45, lot 32 (mater), and now **XIVg**. On two large *zarqālliyya*s from India see respectively my description in *Christie's London 24.9.1992 Catalogue*, pp. 48-49, lot 119 (91 cm diameter), and Sarma, "The *Ṣafīḥa Zarqāliyya* in India", (diameter 55.5 cm, with the original markings of Ibn al-Zarqālluh's *zarqālliyya* on the back). On the European tradition see Poulle, "Saphea", and, most recently, Moreno *et al*., "Spanish Universal Astrolabe".

5.3 An astrolabe engraved with astronomical tables and fitted with an equatorium

One unusual astrolabe devised by Abū Jaʿfar al-Khāzin in Baghdad in the late 10th century contained, in addition to at least one standard astrolabic plate, a series of additional plates (*ṣafāʾiḥ*) bearing various astronomical tables of the kind usually found in astronomical

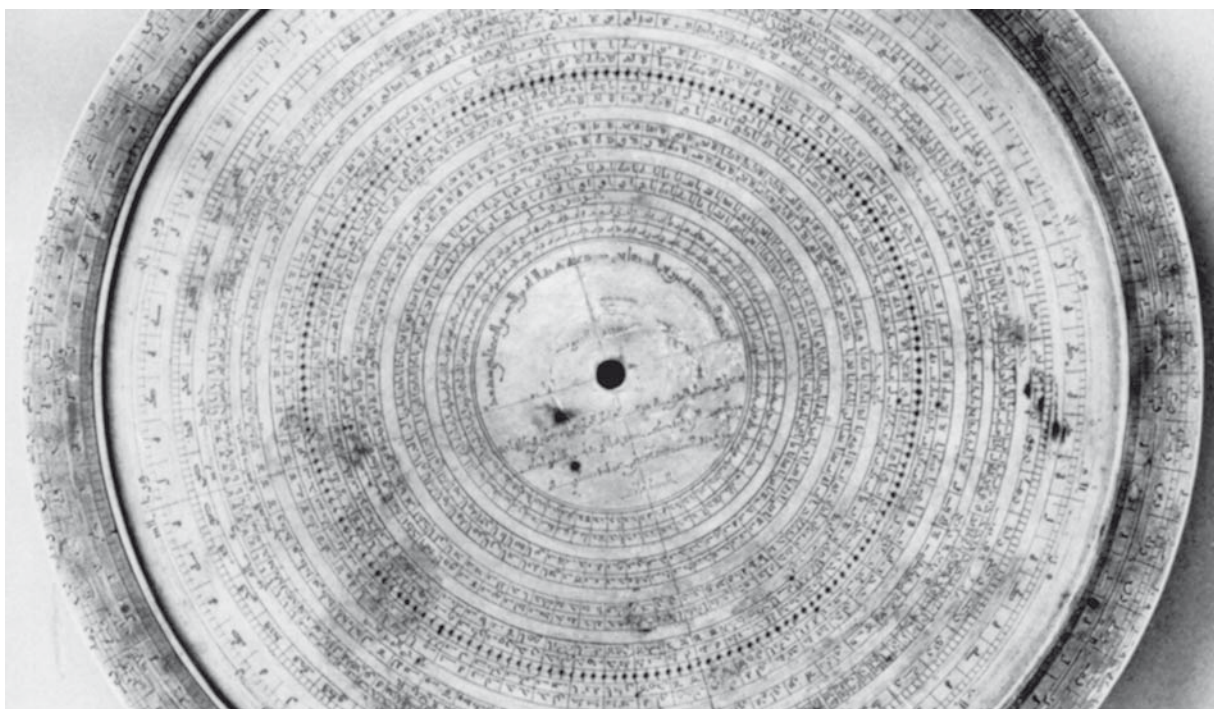



Fig. 5.3.1: Part of the mater of the astrolabe engraved with astronomical tables after the model of Abū Jaʿfar al-Khāzin and made by Hibatallāh al-Asṭurlābī in 513 H [= 1120-21] (#3633). [Photo courtesy of the late Alain Brieux, Paris.]

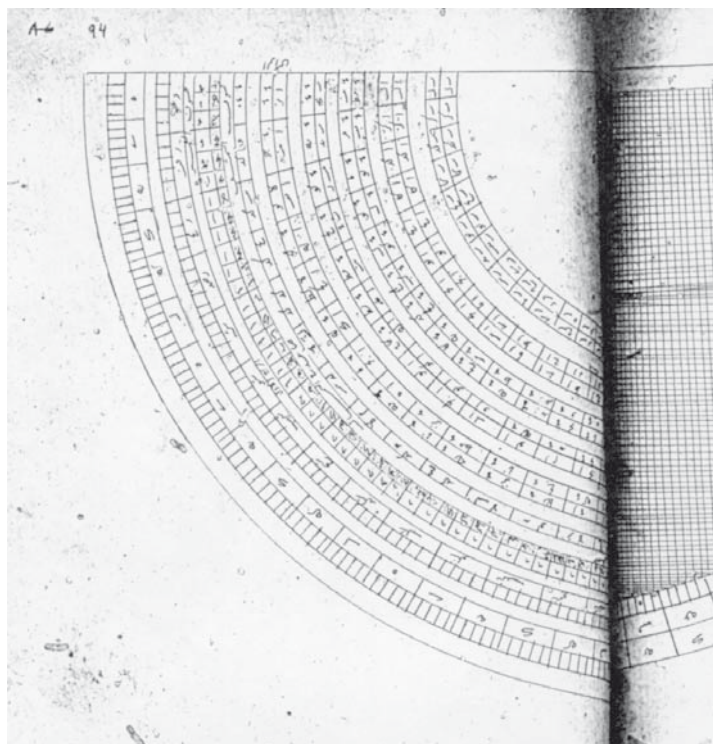
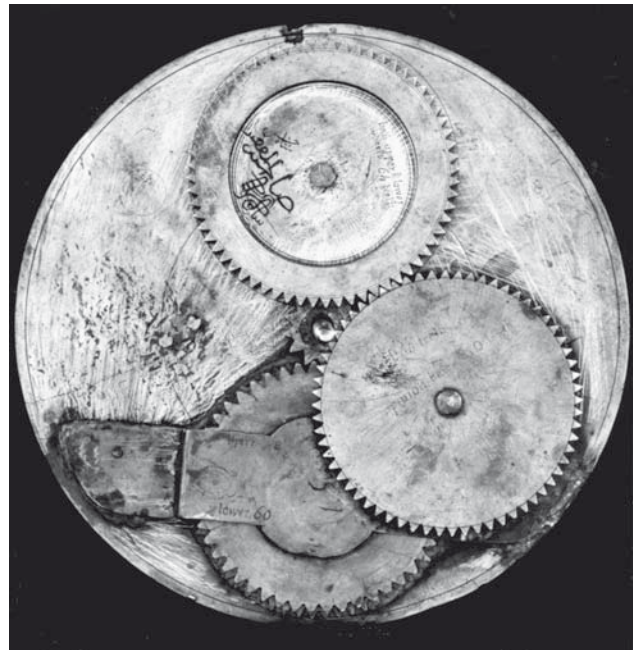



Fig. 5.3.2: An illustration of part of the astronomical tables that should be engraved on the *zīj al-ṣafāʾiḥ*, from the unique copy of the treatise by Abū Jaʿfar al-Khāzin. [From a manuscript in Srinagar (fol. 94r), courtesy of Prof. S. M. Raza Ansari.]

handbooks (*zīj*es). It has been known for some time that al-Khāzin wrote a book to be used alongside his instrument for several later Muslim astronomers of consequence referred to it, but this was apparently no longer extant. A unique example of his *Zīj al-ṣafāʾiḥ*, constructed by the celebrated early-12th-century astrolabist Hibatallāh, was preserved in Munich until 1945, but apparently only photographs of it survived World War II and the first publication in 1980 was based on these. In the early 1990s a copy of the treatise was identified in a library in Srinagar, Kashmir, and in the mid '90s the instrument of Hibatallāh was rediscovered in a vault in the Museum für Indische Kunst in Berlin, and is now housed in the Museum für Islamische Kunst. The treatise is a gold-mine and the instrument has more components than shown by the old photos. For example, an inscription on a set of planetary tables engraved on the mater informs us that the tables are based "on the observations of Ḥabash, the two sons of Mūsā (ibn Shākir), and Sanad ibn ʿAlī". More work needs to be done on these exciting materials.

On the astrolabic *zīj* of al-Khāzin and the associated treatise see the article "Al-Khāzin" by Julio Samsó in EI_2, esp. p. 1182b; *idem*, "*Zīj al-ṣafāʾiḥ*"; and Samsó, "al-Bīrūnī in al-Andalus", esp. pp. 594-601 and 611-612. On the instrument of Hibatallāh see King, "*Zīj al-Ṣafāʾiḥ*". A most welcome preliminary study of the contents of the Srinagar manuscript, or rather, on those parts of it that are to be found on the only available microfilm, is Calvo, "Treatise on the *Zīj al-Ṣafāʾiḥ*".

a

b

Figs. 5.4.1a-b: The back of an astrolabe from 13th-century Isfahan (#5) which displays a luni-solar dial and the appropriate phase of the moon above. This is achieved by the gear mechanism inside the device. [Photo courtesy of the Museum of the History of Science, Oxford.]

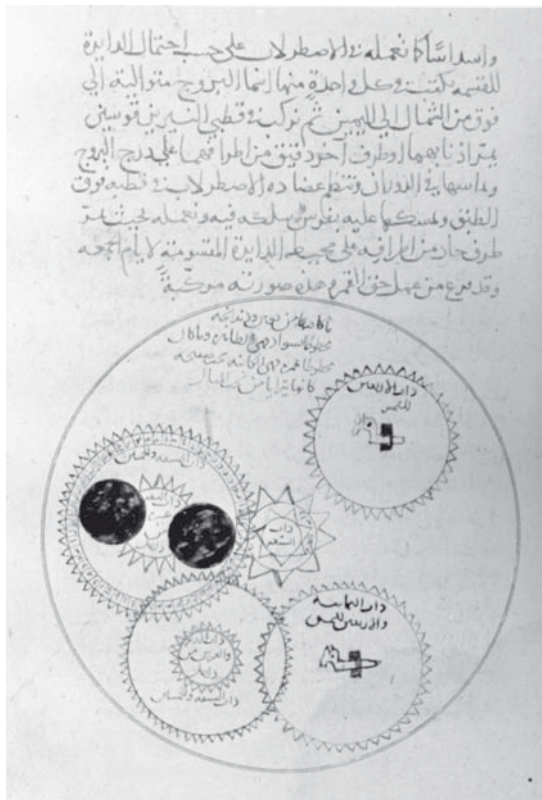
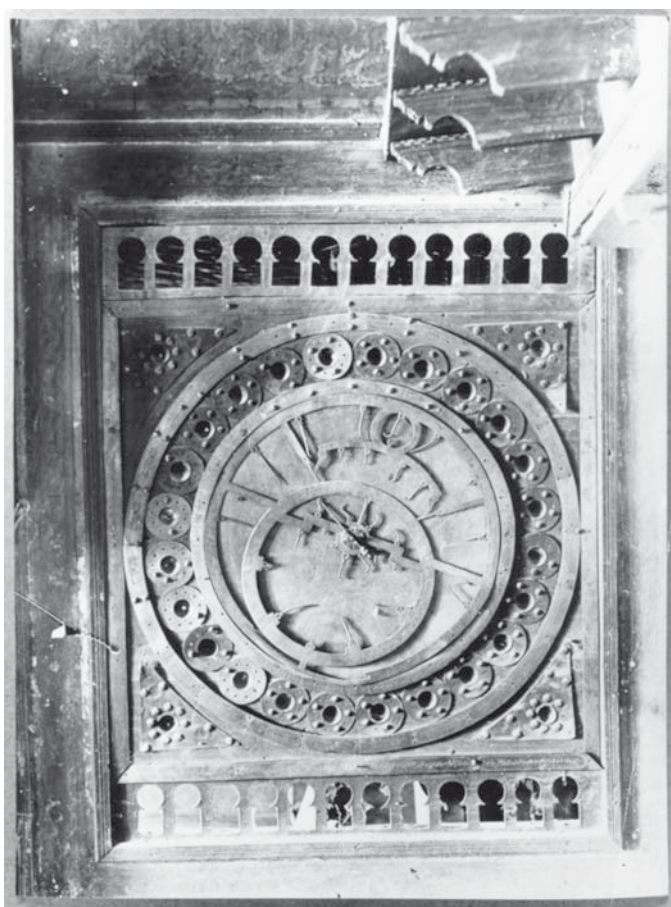



Fig. 5.4.2: The mechanism described by al-Bīrūnī in his book on astrolabe construction to reproduce the solar and lunar motions, as in the later astrolabe shown in **Figs. 5.4.1a-b**. But there is textual evidence that Islamic gear-work reached a much higher level than this. [Taken from MS Istanbul Topkapı Ahmet III 3505, fol. 212r, courtesy of the Topkapı Museum Library.]

Fig. 5.4.3: A French geared astrolabe from *ca*. 1300 (#198). Proof of original Islamic influence is the northern projection used on the rete and plates as well as the horary quadrants for specific latitudes on the back (see **Fig. 6.3.2**). [Courtesy of the Science Museum, London.]

5.4 Geared astrolabes and astronomical clocks

A unique example of an astrolabe fitted with a geared mechanism for reproducing the relative motions of the sun and moon survives from 13th-century Isfahan, made by the highly-competent and innovative Muḥammad ibn Abī Bakr al-Rāshidī al-Ibrī (**Figs. 5.4.1a-b**). We also possess an account of a similar mechanism by the early-11th-century scholar al-Bīrūnī (**Fig. 5.4.2**), and various earlier treatises survive but have not been studied yet. The precise relationship of this kind of mechanism to earlier Greek and Byzantine devices, as well as to later European ones (**Fig. 5.4.3**), remains to be established. Some Italian texts of the early 14th century, if not earlier, provide evidence of the design of astronomical clocks of a highly complex variety with extensive gear mechanisms to reproduce solar, lunar and planetary motions. They seem to represent an Islamic tradition for which we have no evidence from the Islamic world itself.

a

c

Fig. 5.4.4a-c The astrolabic clock in the Qarawiyyīn Mosque in Fez (#4042). The original clock was constructed by Muḥammad al-Ḥabbāk in 685 H [= 1286/87], and this is a replacement. At the hours, balls used to roll out of the appropriate holes in the frame above the clock and thence to the associated construction in the market outside the Mosque. I do not know whether the ensemble has been restored so that it functions again. [Photos from the achives of the late Alain Brieux, Paris, courtesy of Dominique Brieux.]

b

It is known, however, that in 1232 ambassadors of the Ayyubid Sultan al-Ashraf presented to the Emperor Frederick II, whilst in Southern Italy, a kind of planetarium which had "within itself the course of the planets".

A large device for timekeeping resembling an astrolabe was seen by a 14th-century historian in the home of the contemporary Damascene astronomer Ibn al-Shāṭir, and the face of a water-driven astrolabic clock originally made in Fez in the late 13th century survives (in a later replacement) to this day: see **Figs. 5.4.4a-c**. These two instruments and a text in the *Libros del saber* are testimonials to an Islamic tradition on which we have virtually no other information. An inscription preserved in Palermo mentions a *majāna maʿa asṭurlābihā*, "a waterclock with its astrolabe", apparently made for a Merinid Sultan in 1363.

On al-Bīrūnī's description of a gear mechanism (first studied by Eilhard Wiedemann) see now Hill, "Al-Bīrūnī's Mechanical Calendar". On al-Iṣfahānī's geared astrolabe and the unsigned French geared astrolabe see also Gunther, *Astrolabes*, I, pp. 118-120 (no. 5), and II, p. 347 (no. 198). On the astrolabic clocks in Damascus and Fez see the article "Ibn al-Shāṭir" in *DSB* (esp. p. 362), and especially Price, "Fez Water Clocks", and Mayer, *Islamic Astrolabists*, p. 67. On the 14th-century Italian sources based on Islamic originals, see North, "*Opus quarundam rotarum mirabilium*". On water-driven clocks see Hill, *Arabic Water-Clocks*, and on some Iranian clocks see King, *Mecca-Centred World-Maps*, pp. 289-292, and the references there cited.

5.5 The spherical astrolabe

An Islamic development of the planispheric astrolabe was the spherical astrolabe, an instrument in which a spherical frame bearing markings representing the ecliptic and fixed stars could be rotated over a sphere with markings for the horizon and altitude circles of any locality and the hours—see **Fig. 5.5.1**. The instrument has the advantage over the planispheric astrolabe that it was universal, that is, it can be used for any latitude. A series of treatises was written on the instrument between the 10th and 17th centuries, but it does not appear to have been widely used, and just two examples survive, only one of which is complete.

On the spherical astrolabe see Seemann, *Das kugelförmige Astrolab*; and Lorch, "The *sphaera solida* and Related Instruments". On the two surviving examples, see Maddison, "15th-Century Spherical Astrolabe", and Canobbio, "Fragment of a Spherical Astrolabe". See also Pellat, "L'astrolabe sphérique d'al-Rūdānī", and Janin, "Ar-Rūdānī sur l'astrolabe sphérique", as well as Poulle, "L'astrolabe sphérique dans l'occident latin".

5.6 The linear astrolabe

The ingenuity of the mathematician Sharaf al-Dīn al-Ṭūsī (*fl*. Iran, *ca*. 1200) was such that he conceived a linear astrolabe, appropriately called *ʿaṣā 'l-Ṭūsī*, that is, "al-Ṭūsī's baton". His instructions on the use of the instrument, as reproduced by the 13th-century Cairo astronomer

Fig. 5.5.1: The sole surviving complete Islamic spherical astrolabe (#8001), made somewhere between Egypt and Iran in the year 885 H [= 1480/81] by a man who identifies himself simply as "Mūsā". It is still a matter of debate whether this instrument was developed from the celestial sphere or from the planispheric astrolabe. The spherical astrolabe was not widely used, no doubt because of the difficulty involved in its construction. Also, although it is described in the 13th-century *Libros del saber*, it was apparently not introduced to the Latin West. [Courtesy of the Museum of History of Science, Oxford.]

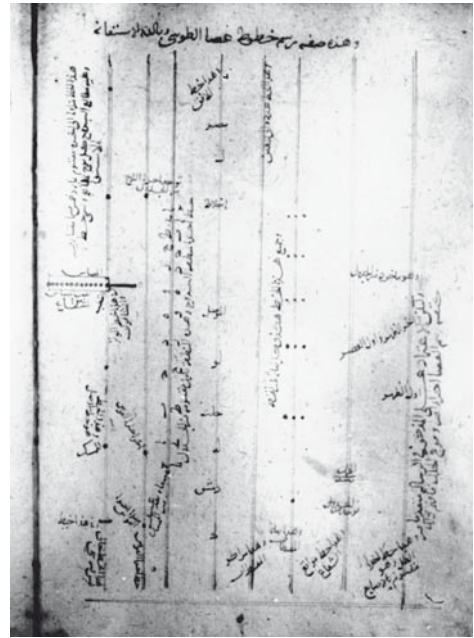



Fig. 5.6.1: The scales for a linear astrolabe illustrated in a copy of a treatise on the instrument by the 12th-century mathematician Sharaf al-Dīn al-Ṭūsī. Essentially the markings represent those on the meridian of a standard astrolabe plate, and two threads with movable beads that are attached at various significant points along the meridian replace the rete. The resulting "slide-rule" can be used to solve all the standard astrolabe problems but only for a specific latitude. The instrument was known in al-Andalus but was apparently not transmitted to Europe. [From MS Istanbul Topkapı Ahmet III 3505,2, courtesy of the Topkapı Museum Library.]

al-Marrākushī, have been studied; his original treatise has not. The instrument consists of a series of scales marked on a baton representing the meridian for a specific latitude—see **Fig. 5.6.1**. Two of the scales represent the intersections with the meridian of the altitude circles and the concentric circles representing the stereographic projections of the zodiacal signs; the basic idea is that any circle on the standard planispheric astrolabe can be represented on the baton by the position of its centre and its radius. Threads are attached to the baton, and with these and the various scales one can perform the standard operations of an astrolabe. Angles are measured by means of an additional scale of chords. The device is brilliant in its conception but impractical, and no examples are known to have survived.

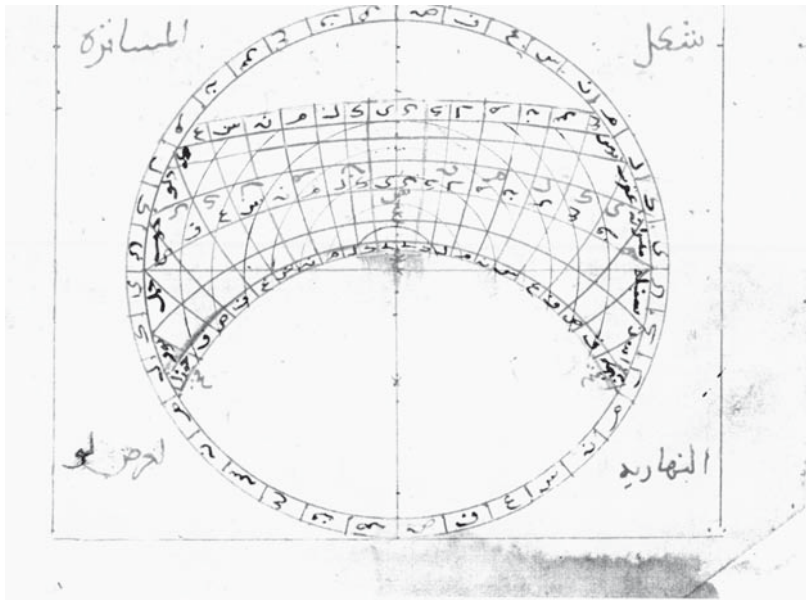



Fig. 5.7.1: An instrument based on a horizontal stereographic projection, from Najm al-Dīn's treatise. The instrument is labelled *musātara*, a term whose meaning is obscure, and the author proposes two types, one for day and the other for the night. On different, less successful, Andalusī tradition see Casulleras, "Andalusī Sundial". [From MS Dublin CB 102, fol. 73r, courtesy of the Chester Beatty Library.]

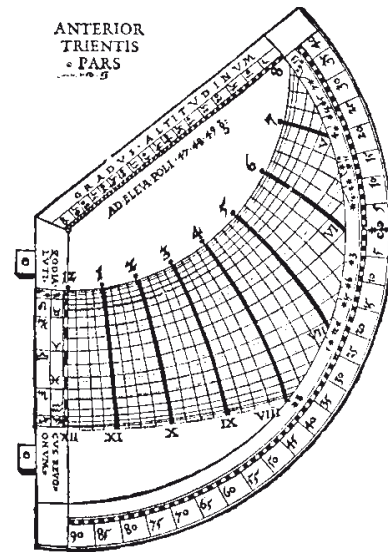



Fig. 5.7.2: One of several instruments of the same kind illustrated in Renaissance treatises, this one by Peter Apian *ca*. 1540. [From Janin, "Projection horizontale", p. 306; see also Röttel. ed., *Peter Apian*, pp. 240-243.]

On the linear astrolabe see Carra de Vaux, "L'astrolabe linéaire"; Michel, "L'astrolabe linéaire", also *idem*, *Traité de l'astrolabe*, pp. 115-123; and Puig, "El astrolabio lineal en al-Andalus".

5.7 Horizontal orthogonal projections

Another rare device was an instrument bearing an orthogonal projection of the celestial sphere in the plane of the horizon of a specific latitude. The projection might display altitude circles (concentric about the zenith), declination curves (projections of the day-circles of the sun for each, say, 30° of solar longitude), and hour-angle curves. A solar longitude scale can be placed about the east and/or west points, indicating also the corresponding directions of sunrise (that is, the solar rising amplitudes). It is of less practical use than a combination of an ecliptic ring and standard astrolabe plate, and is best used for finding the hour-angle from a given solar altitude. Such an instrument is also featured by the Mamluk astronomers al-Marrākushī and Najm al-Dīn al-Miṣrī: see **Fig. 5.7.1** and also **Fig. 5.7.2** for a Renaissance European example. A related, but less serious instrument is called a sundial by the Andalusī Ibn Khalaf al-Murādī: see **7.2**.

See Janin, "Projection horizontale"; and Charette, *Mamluk Instrumentation*, pp. 87-94.

CHAPTER 6

QUADRANTS

There are essentially four varieties of Islamic quadrant:
(1) the trigonometric quadrant, for solving numerically problems of trigonometry, usually those deriving from spherical astronomy;
(2) the horary quadrant, for reckoning time by the sun;
(3) the astrolabic quadrant, developed from the astrolabe; and
(4) the universal *shakkāzī* quadrant, for solving problems of spherical astronomy for any latitude.

Each of these was invented by Muslim astronomers. The early history of the different kinds of quadrants has only recently been investigated for the first time, and the problems associated with their transmission to Europe now have to be considered afresh.

On the quadrant in Islam see already Schmalzl, *Zur Geschichte des Quadranten bei den Arabern*, (contains a useful glossary of Arabic terms on pp. 133-138); and the overview in the article "Rubʿ" in EI_2. New insights are in Charette, *Mamluk Instrumentation*.

6.1 The trigonometric quadrant

The trigonometric quadrant was developed in Baghdad in the 9th century and remained popular for a millennium. Originally it was devised to solve just one problem: the determination of time as a function of solar altitude and solar meridian altitude using an approximate formula adequate for low latitudes (that is, up to *ca*. 36°): see **XI-1.2**, **2** and **XIIa-3**. In the 10th century the sine quadrant was developed into a calculating device for all problems of spherical astronomy; as such we find it presented in the treatise entitled *Zīj al-ṣafāʾiḥ* of Abū Jaʿfar al-Khāzin: see **Figs. 6.1.1-2**. With markings resembling modern graph-paper, fitted with a cord attached at the centre of the quadrant and carrying a movable bead, one can solve numerically the most complicated problems of medieval trigonometry, such as, for example, the problem of determining the qibla for any locality: see **Fig. 6.1.4**. Often a sine grid of one kind or another would be incorporated on the back of an astrolabe.

On the use of the trigonometric quadrant as described in some of the earliest texts see King, "al-Khwārizmī", pp. 29-31; Lorch, "Sine Quadrant"; and now **XI-8.1**. On the use of the instrument for solving one of the most complicated trigonometric problems confronting Muslim astronomers, see King, "al-Khalīlī's Qibla-Table", esp. pp. 109-120.

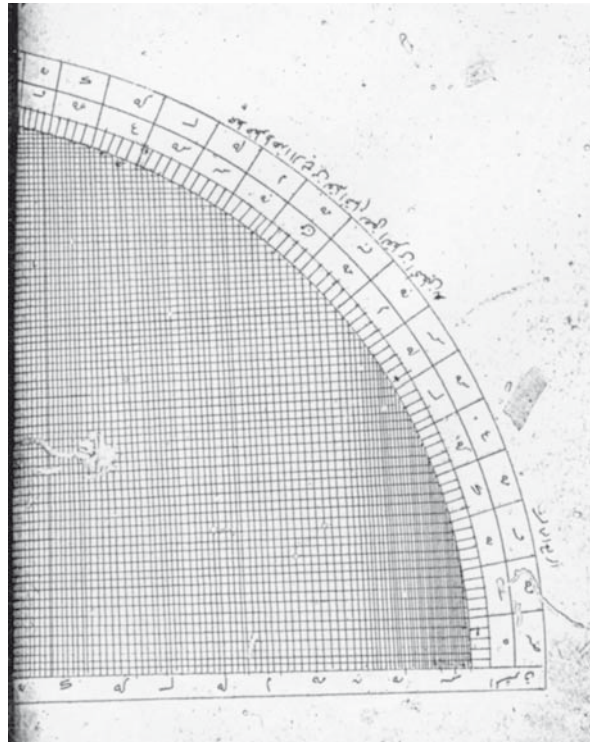



Fig. 6.1.1: The sine quadrant illustrated in a treatise on the *zīj al-ṣafā'ih*, "the *zīj* on the plates (of an astrolabe)" by Abū Jaʿfar al-Khāzin, compiled *ca*. 950. [From a manuscript in a library in Srinagar, Kashmir, courtesy of Professor Raza Ansari.]

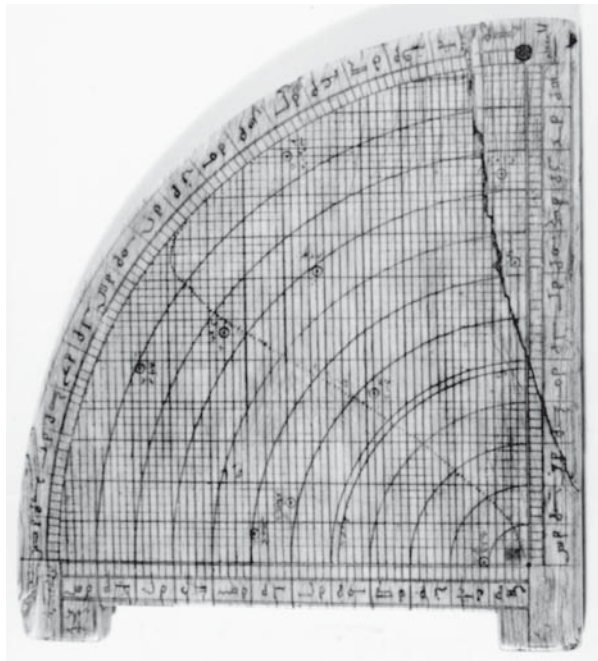



Fig. 6.1.3: The sine quadrant on the back of an ivory quadrant made in Damascus in 741 H [= 1340/41] by Abū Ṭāhir (#5009). See **Fig. 1.6** for the front. [Courtesy of the Benaki Museum, Athens.]

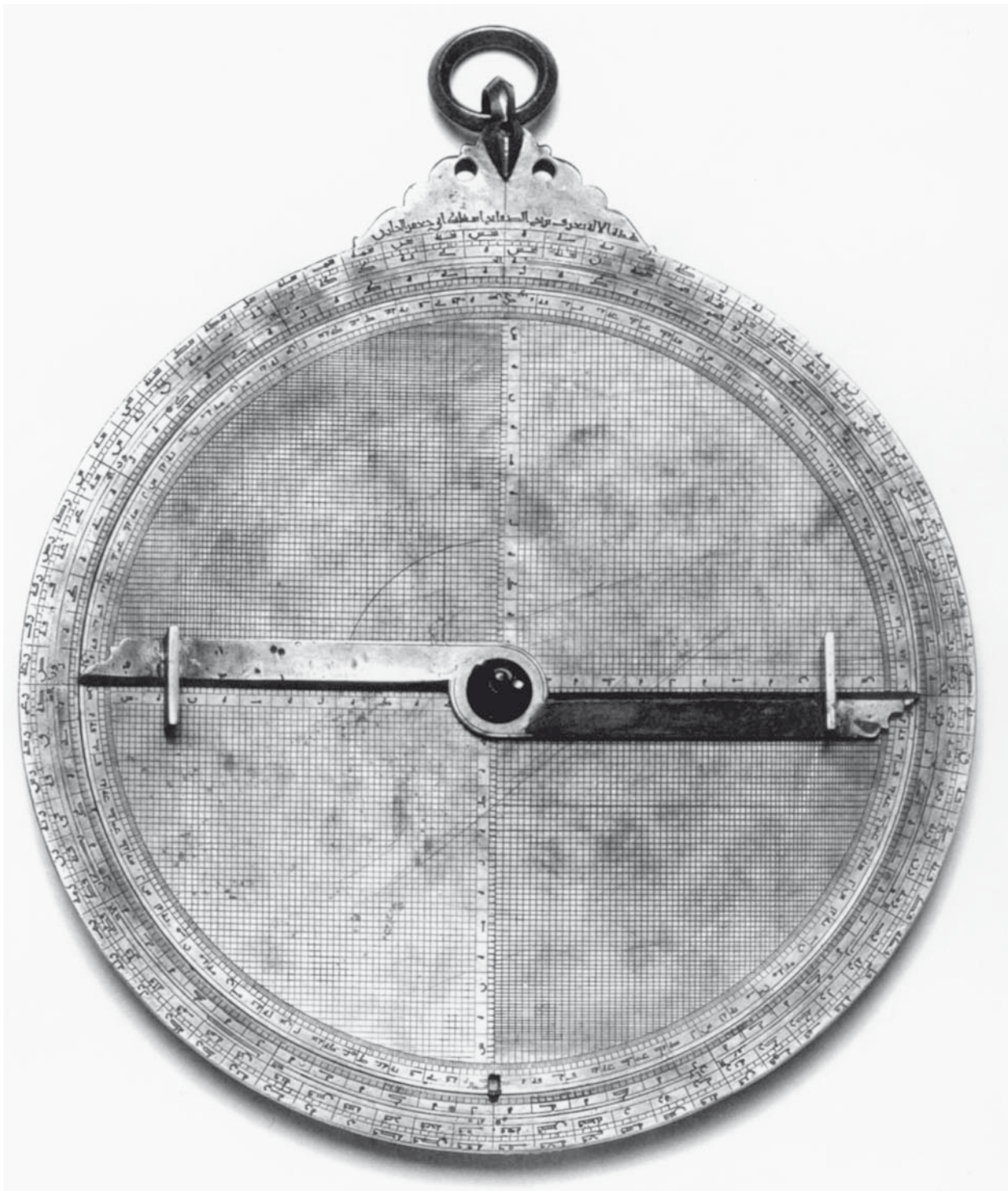



Fig. 6.1.2: The sine quadrants on one plate of the only surviving *zīj al-ṣafāʾiḥ*, made by Hibatallāh in 514 H [= 1120/21] (#3633). [Courtesy of the Museum für Islamische Kunst, Berlin.]

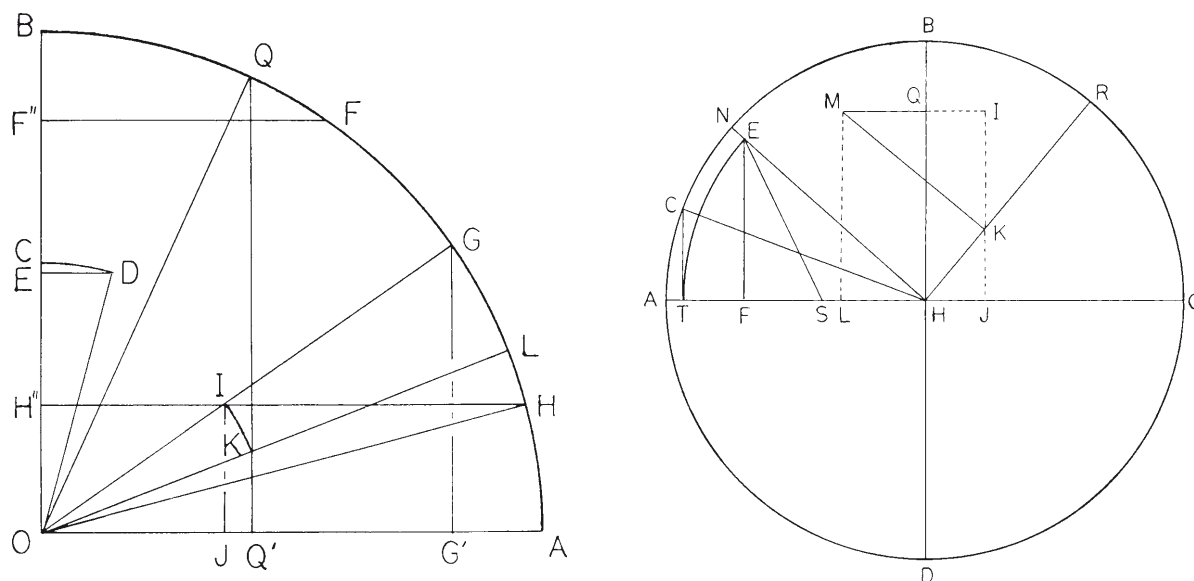



Fig. 6.1.4: Abū ʿAlī al-Marrākushī (Cairo, *ca*. 1280), when writing on the sine quadrant, proposed this procedure in two stages for finding the qibla from the latitudes of two localities and their longitude difference. One has to be adept at entering arguments and zapping about with a bead on a movable thread to convert arcs to sines of arcs, and to perform multiplications; these operations are not for the faint-hearted. In the first figure, mark AC = ϕ_M, AD = ϕ, and FG = ΔL. Then take AI = $\phi+\phi_M$, and I'J" is made equal to FH. AJ then measures h, the altitude of the zenith of Mecca above the local horizon. In the second figure, we draw arc J"K and the perpendicular KL Now from C construct N and NP, then R. Next mark OS equal to MR From J" construct J and J' and T, then draw SU to cut quadrant TJ' at U, finally produce OU to Q. Then AQ measures the qibla. [From King, "al-Khalīlī's Qibla Table", pp. 118-119, with full instructions and explanations.]

6.2 The universal horary quadrant

The horary quadrant bears either a series of markings for the seasonal hours, which are twelfth divisions of the length of daylight, or for the equinoctial hours. In the first case, the markings serve all latitudes (the underlying formula—already mentioned above—being approximate); in the second case, they serve one specific latitude. When one edge of the quadrant is aligned towards the sun, a bead on a plumb-line attached at the centre of the quadrant indicates the time of day. A text from 9th-century Baghdad preserved in Cairo describes the horary quadrant with both fixed and movable cursor and shadow-box superposed, previously thought to have been a much later European invention (the so-called *quadrans vetus*)—see **Fig. 6.2.1**. Universal horary quadrants of this kind are common on Islamic astrolabes from the 10th century to the 19th. Also they frequently appear on European instruments, even though the underlying formula, which had long been forgotten, is not accurate enough in higher latitudes to yield acceptable results for the time of day.

Previous studies of the universal horary quadrant include North, "Astrolabes and the Hour-Line Ritual", (assumes that a solar scale is essential and overlooks the fact that the error is latitude-dependent); Lorch,

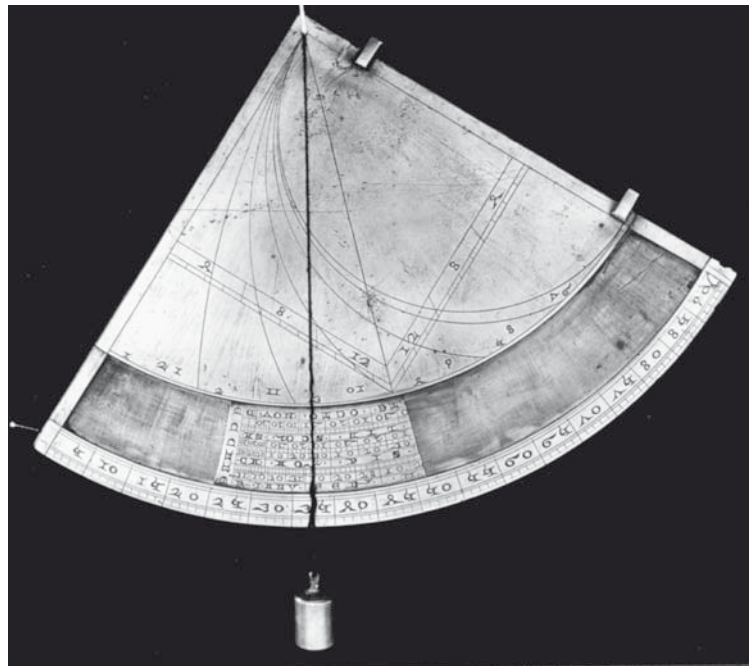



Fig. 6.2.1: A *quadrans vetus* (#5502), very popular in Europe from the 12th century, when the first Latin texts on its use appeared, until the 16th century, but first described in an Arabic treatise from 9th-century Baghdad. The horary markings themselves serve all latitudes, and the calendrical scale to facilitate operations is actually superfluous to the underlying mathematical operation. Only one-half of the cursor survives on this instrument. See also **Fig. XIIa-2c** for a complete example. [Courtesy of the Museum of the History of Science, Oxford.]

"Universal Horary Quadrant"; and Archinard, "Unequal Hour Diagram", a useful mathematical investigation. See now **XIIa**.

6.3 Latitude-specific horary quadrants

Two horary quadrants for specific latitudes survive, one from Nishapur and the other from Cairo, both from the 13th century: see **Figs. XIIIc-13** and **A2**. Others are attested on the backs of astrolabes from the 10th century onwards: see **Figs. XIIIc-8.1a** and **6.3.1**. Such markings, in both forms, also became popular in Europe: see **Figs. 6.3.2-3**. More research needs to be done to determine whether certain highly sophisticated Ottoman quadrants with different sets of horary markings (**Fig. 6.3.4**) are entirely Islamic in their inspiration (this is my opinion) or reflect some European influence (as suggested by François Charette). A simple variety of horary quadrant that I label zodiacal quadrant, displaying only solar meridian altitudes or solar altitudes at the afternoon prayer (and from the 16th century onwards, also the altitude of the sun when it is in the qibla) was often included on the backs of astrolabes from the 12th century onwards: see **Fig. XIIIc-IIb**.

On latitude-specific horary quadrants see King, "al-Khwārizmī", pp. 30-31; Viladrich, "Horary Quadrants"; and especially Charette, *Mamluk Instrumentation*, pp. 116-136.

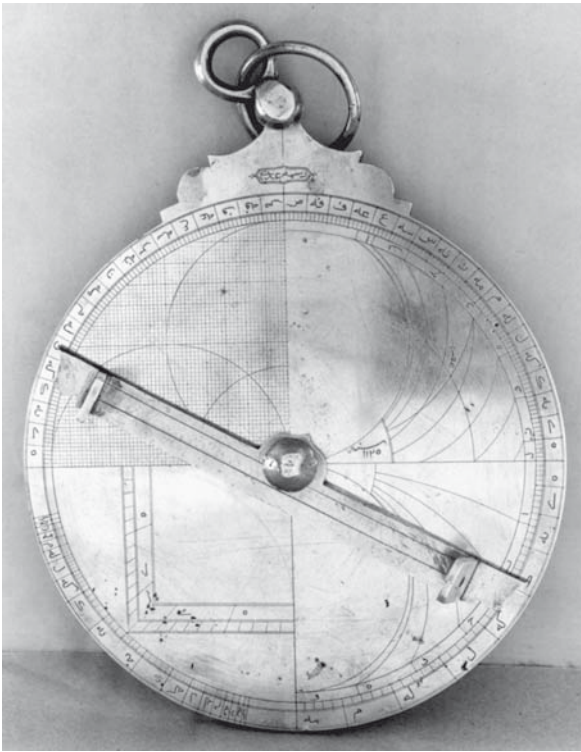



Fig. 6.3.1: The back of an Ottoman Turkish astrolabe made by ʿAbdī in 1125 H [= 1713/14] (#1222) which displays a universal horary quadrant (lower right) and a quadrant specifically for latitude 41°, serving Istanbul (upper right). Both of these features, as well as the trigonometric quadrant (upper left) and shadow-scales (lower left) have a history that can be traced back to 9th-century Baghdad. [Courtesy of the Museum of the History of Science, Oxford.]

Fig. 6.3.2: A double horary quadrant for a specific latitude on the back of the French astrolabe (#198) shown in **Fig. 5.4.3**. Such quadrants are described in earlier Abbasid and Andalusī texts. [Courtesy of the Science Museum, London.]

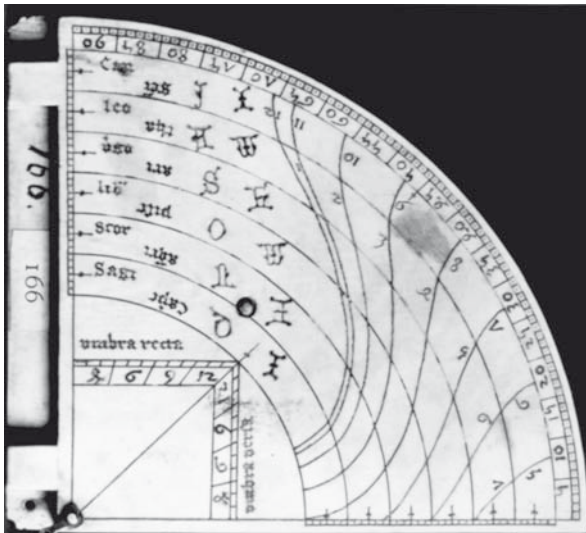
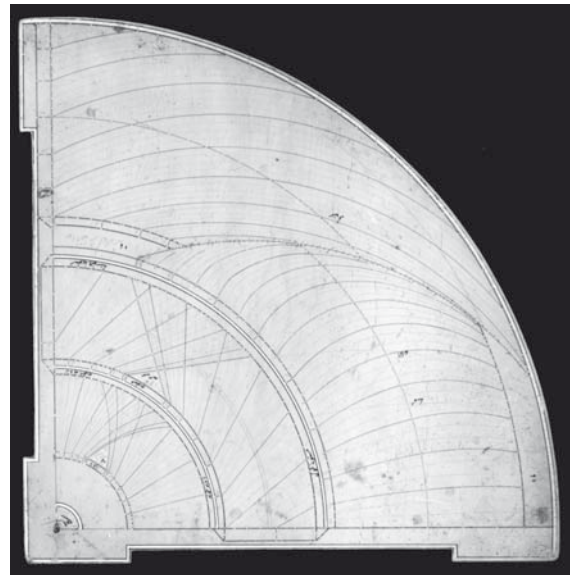



Fig. 6.3.3

Fig. 6.3.4

6.4 The astrolabic quadrant

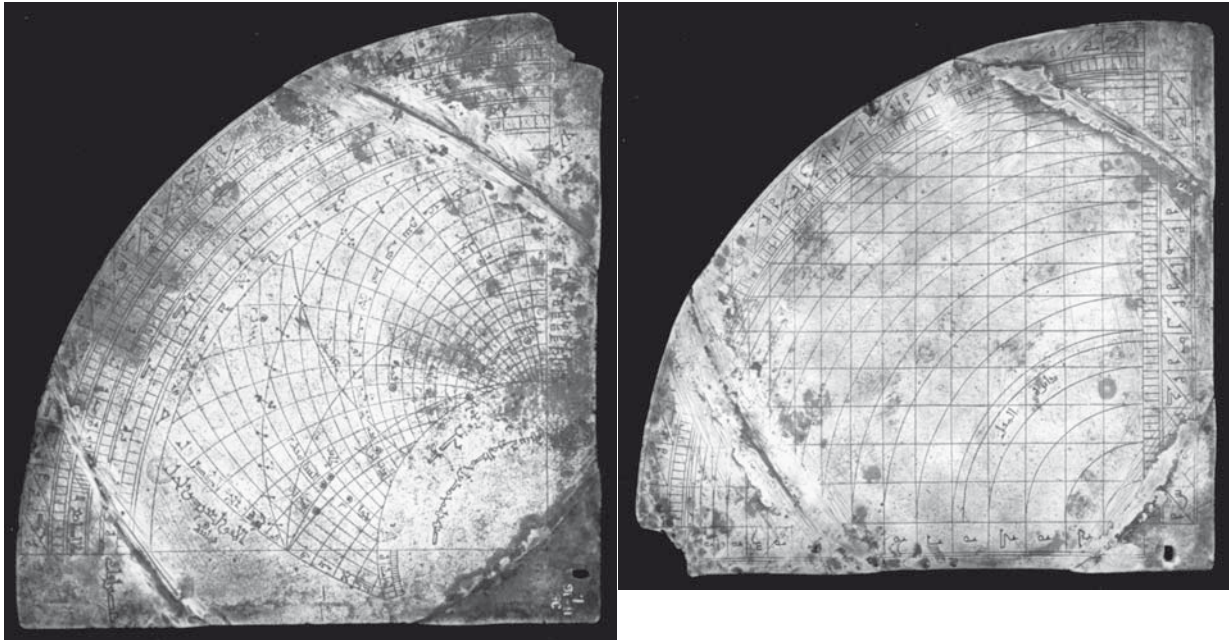
Considerable mystery surrounds the invention of the astrolabic quadrant. The basic idea is simple: since the markings on a standard astrolabe plate are symmetrical with respect to the meridian, one uses just half of such a plate engraved on a quadrant (only markings above the horizon are incorporated). The rete is replaced by a cord attached to the centre of the quadrant, and this carries a bead that can be moved to represent the position of the sun or a fixed star, either of which can be found from markings for the ecliptic and star positions that are now included on the quadrant itself. The astrolabic quadrant is such a handy device that by the 16th century it had generally replaced the astrolabe in most parts of the Islamic world except Morocco on the one hand and Iran and India on the other—see **Figs. 1.6** and **6.4.1-2**. Most surviving astrolabic quadrants are of Ottoman Turkish provenance, although we do have a few Mamluk examples from the 14th century.

Figs. 6.4.1a-b: One of several astrololabic quadrants by al-Mizzī that survive (#5003), in spite of the fact that someone had a good try at destroying it. This is a basic instrument, and Mamluk astronomers made considerably more complicated ones: see, for example, **Figs. V-9.2-3** and **XIVb-6.1**. It was made by al-Mizzī in 727 H [= 1326/27], and has never been illustrated previously. The front of the instrument bears astrolabic markings for the latitude of Damascus, 33;30°, and the back bears markings for the Sines and Cosines, as well as radial circles, including one for the solar declination, with radius 24 ($\approx$ Sin ε). [Courtesy of The British Museum, London.]

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Fig. 6.3.3: An ivory horary quadrant for the latitude of Vienna made in 1438 (#5510). On the back there is a solar-lunar volvelle. For a survey of instruments made in Vienna in the 15th century as well as medieval instruments preserved in Austrian collections, see King, "Astronomical Instruments between East and West", pp. 183-191. Courtesy of the Kunsthistorisches Museum, Vienna.]
Fig. 6.3.4: An Ottoman quadrant made by Shukr Zāde in 1178 H [= 1764/65] displaying three different kinds of horary markings (#5152). At least the outer set is of a kind known already from much earlier Islamic sources. [Photo by Prof. Owen Gingerich, courtesy of the Egyptian National Library, Cairo.]

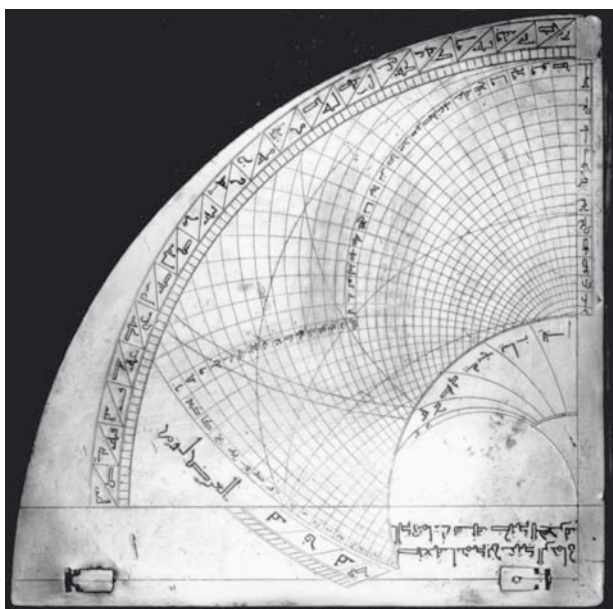



Fig. 6.4.2: An astrolabic quadrant for the latitude of Tunis, made by Aḥmad ibn ʿAbd al-Raḥmān al-Dahmānī in 854 H [= 1450/51] (#5021). [Courtesy of the Museo Arqueológico Nacional, Madrid.]

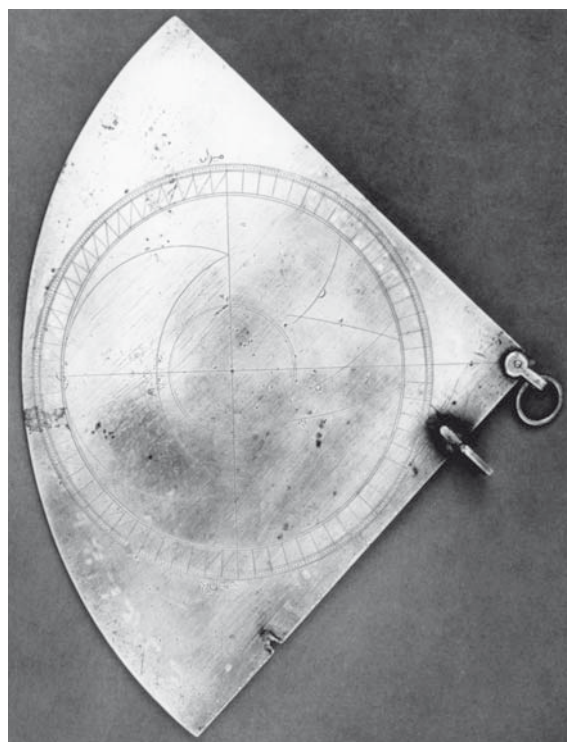



Fig. 6.4.3: A Maghribi quadrant from *ca*. 1700 (#5022) with a curious set of stereographic markings and cryptic inscriptions (each limited to a single Arabic letter) that enable the user to find the times of the astronomically-defined times of Muslim prayer and the time when the sun is in the direction of Mecca. Investigation of the markings in the light of medieval geographical coordinates establishes that it was intended specifically for use in Marrakesh. [Courtesy of the Adler Planetarium, Chicago, Ill.]

Until recently, the earliest known treatises on the use of the astrolabic quadrant were those compiled in Syria in the 14th century. Yet not one of the authors of these treatises claims to have invented the instrument. A manuscript preserved in Istanbul deals with the use of the astrolabic quadrant: it is of Egyptian origin and is datable to the 12th century; however, the author makes no claim to have invented the instrument: see **Fig. 6.4.4**. This precious source was discovered in the 1970s but is not yet published.

Studies of individual astrolabic quadrants are Morley, "Arabic Quadrant" (1860); Dorn, "Drei arabische Instrumente" (1865), pp. 16-26; and, more recently, Fehérvári, "Quadrant of al-Mizzī"; Janin & Rohr, "Deux astrolabes-quadrants turcs"; in *Paris IMA 1993-94 Exhibition Catalogue*, p. 348, no. 333, and pp. 442-443, no. 337, now in **XIVb-6.1** and **10**.

6.5 The universal quadrant

New kinds of trigonometric grids were invented in Syria in the 14th century as alternatives to the trigonometric quadrant, and for these the astronomers who invented them have left us treatises on their use. The universal *shakkāzī* quadrant with one or two sets of *shakkāziyya* grids is a singularly useful device: see **Fig. 6.5.1**.

A few examples of other grids survive, and they were apparently quite popular in Egypt, Syria and Turkey for several centuries. Some of these grids were of very considerable so-

Figs. 6.4.4a-c: The title, first page and colophon of the earliest known treatise on the astrolabic quadrant. The manuscript was copied some time in the 12th century (see **XIIa-11**). The author, an Egyptian, makes no claim to have invented the instrument but describes all the features that are common on such instruments, such as an additional universal horary quadrant and scale for the solar declination and the altitude of the sun at the ʿ*aṣr* prayer. [From MS Istanbul Haci Mahmud Efendi 5713, fols. 10v-11r and 34v, courtesy of the Süleymaniye Library.]

phistication, such as the one on the back of the astrolabe of Ibn al-Sarrāj (see **Fig. XIVb-5.1b**). Most of these grids serve the same purpose of providing universal solutions to the problems of spherical astronomy: see **VIb** and some examples in **Figs. VIb-8.1-3** and **XIIa-6a-b**.

On universal quadrants see Samsó & Catalá, "Cuadrante šakkāzī", and Samsó, "Cuadrante šakkāzī", (on the single *shakkāzī* quadrant); and King, "The *Shakkāziyya* Quadrant of al-Māridīnī" (on the universal *shakkāzī* quadrant).

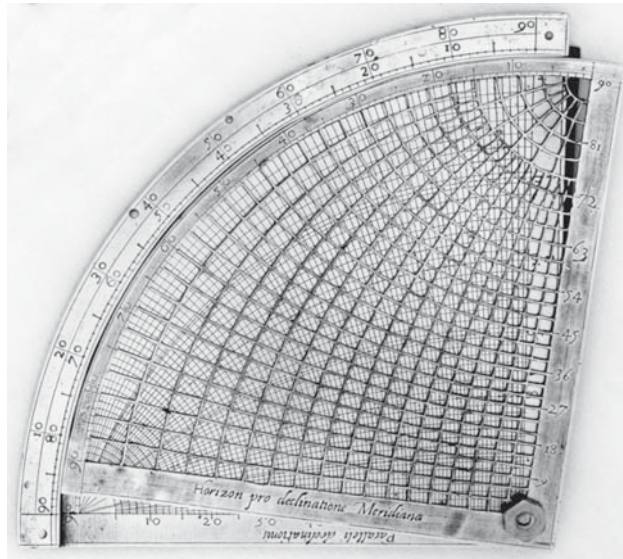



Fig. 6.5.1: A double *shakkāzī* quadrant (#2079) as described by Jamāl al-Dīn al-Māridīnī *ca*. 1400. This was made in Spain *ca*. 1580 by an instrument-maker in the Louvain tradition. For more information see *Madrid FCA 1997 Exhibition Catalogue*, pp. 190-191 (no. A19), and *Chicago AP Catalogue*, I, pp. 130-132 (no. 36). [Courtesy of the Adler Planetarium, Chicago, Ill.]

6.6 *Caveat*: the new quadrant of Profatius

> " ... it is rather complicated, although not impossible, to use the *quadrans novus* when a more precise determination of time is demanded than that obtainable with the 'universal' hour lines of the *quadrans vetus*." Elly Dekker, "*Quadrans Novus*" (1995), p. 6. [Dekker, who alas does not state how this can be done, omits to mention that it is not possible to determine time accurately with the astrolabic markings of the *quadrans novus* because they are to be used in conjunction with the approximate horary markings of the *quadrans vetus*.]

It should be mentioned that the *quadrans novus* of Profatius (*fl*. S. W. France, *ca*. 1300) is a bastard device consisting of a universal horary quadrant encumbered by a shadow-square, that is, a *quadrans vetus*, and fitted with a stereographic projection of both the ecliptic and a set of horizons superposed on one side: see **Fig. XI-8a**. On the other side, there may be a trigonometric quadrant on the other for solving numerically the kind of problems—such as timekeeping using an accurate procedure (!)—which cannot be solved mechanically on the first side. This development of this instrument out of the Islamic/European *quadrans vetus* and trigonometric quadrant, and especially the provision of the ecliptic and horizons (albeit without the altitude circles of the astrolabic quadrant developed earlier in Egypt), seems to have been Profatius' own idea, and it became quite popular in Europe. It was, however, unknown in the Islamic world. Modern accounts of Islamic astrolabic quadrants invariably confuse the two instruments.

On the quadrant of Profatius see, for example, Poulle, "*Quadrans novus*"; and Dekker, "*Quadrans novus*". For the latest on the misunderstanding of its origins see *London Khalili Collection Catalogue*, I, p. 266, and King, "Review", col. 255. See now **XI-10.3** and **XIIa-8**.

CHAPTER 7

SUNDIALS

The Muslims inherited the sundial from their Hellenistic predecessors. Presumably the Arabs found sundials in use in some of the territories into which they expanded in the 7th century. In Damascus about the year 715 the Umayyad Caliph ʿUmar ibn ʿAbd al-ʿAzīz is said to have used a sundial, presumably marked with the seasonal hours, in order to regulate his prayers; this was probably of Graeco-Roman provenance. (The record of his interest in this sundial also illustrates that at that time the daytime prayers were still defined in terms of the seasonal hours.)

In its essence the sundial consists of an object (called a gnomon) for casting a shadow, and a series of markings on a surface which enable the user to observe the progress of the variable shadow across the surface and read off the time of day. Most, but not all, medieval sundials were of the plane horizontal or vertical varieties, with markings consisting of a family of lines for each hour of daylight and three curves which are the shadow traces at the equinoxes and at the two solstices.

7.1 Treatises on gnomonics and sundial construction

Muslim astronomers made several notable contributions to the theory and construction of sundials. We may cite the treatise of Thābit ibn Qurra, written in Baghdad around the end of the 9th century. This deals with the transformation of celestial coordinate systems based on three planes: (1) the horizon, (2) the celestial equator, and (3) the plane of the sundial. For the latter, the sundial may be in the plane of (a) the horizon; (b) the meridian; (c) the prime vertical; (d) perpendicular to (c) with an inclination to (b); (e) perpendicular to (b) with an inclination to (c); (f) perpendicular to (a) with an inclination to (b), and lastly, (g) perpendicular to (f) with an inclination to (a), that is, skew to (a), (b) and (c). Ibrāhīm ibn Sinān, in the first half of the 10th century, authored another remarkable treatise on gnomonics, in which he proved for the first time that the seasonal hour-lines are not straight lines. Both of these treatises are highly theoretical, as distinct from the works of Ḥabash and Ibn al-Ādamī (see below).

Second, Muslim astronomers compiled tables of coordinates to facilitate the construction of the simple *horizontal* sundial displaying the seasonal hours for a specific latitude, just as they did for the construction of astrolabes—see **Fig. 7.1.1-5**. These tables have no parallel in medieval or Renaissance Europe. Ḥabash al-Ḥāsib, working in Baghdad in the early 9th century, compiled tables displaying, for ten different latitudes, values of the following functions for each seasonal hour at the solstices: the solar altitude, the solar azimuth, and the length of the shadow cast by a gnomon. The shadow lengths and azimuths are simply the polar coordinates of the points of intersection of the solstitial shadow traces with the lines representing the seasonal hours, and with these the construction of the sundial is reduced to a task for a mason. (In the

Fig. 7.1.1: An extract from the sundial tables for sundial construction by Ḥabash al-Ḥāsib (attributed to al-Khwārizmī in this unique copy). These subtables serve latitudes 38° and 40°, with a more detailed table for latitude 34°, Samarra, the new Abbasid capital that replaced Baghdad during the period 836-892. See also **Figs. I-4.1.1a** and **VIa-10.1**. [From MS Istanbul Ayasofya 4830, fol. 234r, courtesy of the Süleymaniye Library.]

Fig. 7.1.2: An extract from the auxiliary tables of coordinates for the construction of vertical sundials in a treatise on gnomonics by the 10th-century astronomer Ibn al-Ādamī. These tables merit detailed investigation. See further Sezgin, *GAS*, VI, pp. 216-217. [From MS Paris BNF ar. 2506, fol. 33v, courtesy of the Bibliothèque Nationale de France.]

unique manuscript these tables are incorrectly attributed to al-Khwārizmī.) Several later Muslim astronomers prepared such tables for specific latitudes. Other treatises, such as those by the Alphonsine astronomers and the Andalusī Ibn al-Raqqām in Tunis *ca*. 1300, present instructions for marking sundials by geometrical construction.

In Baghdad in the 10th century, Ibn al-Ādamī compiled a set of auxiliary tables to facilitate marking the curves on *vertical* sundials inclined at any angle to the meridian for any latitude. A set of tables of Cartesian coordinates for marking vertical sundials by the late-13th-century Egyptian al-Maqsī contains 90 subtables for each degree of inclination to the local meridian, computed for the latitude of Cairo. Such tables would have been very useful to the astronomers who constructed sundials on the walls of so many of the mosques of medieval Cairo.

Third, Muslim astronomers developed the universal polar sundial, the universal equatorial sundial, the universal inclined sundial, and the gnomon aligned towards the celestial pole for

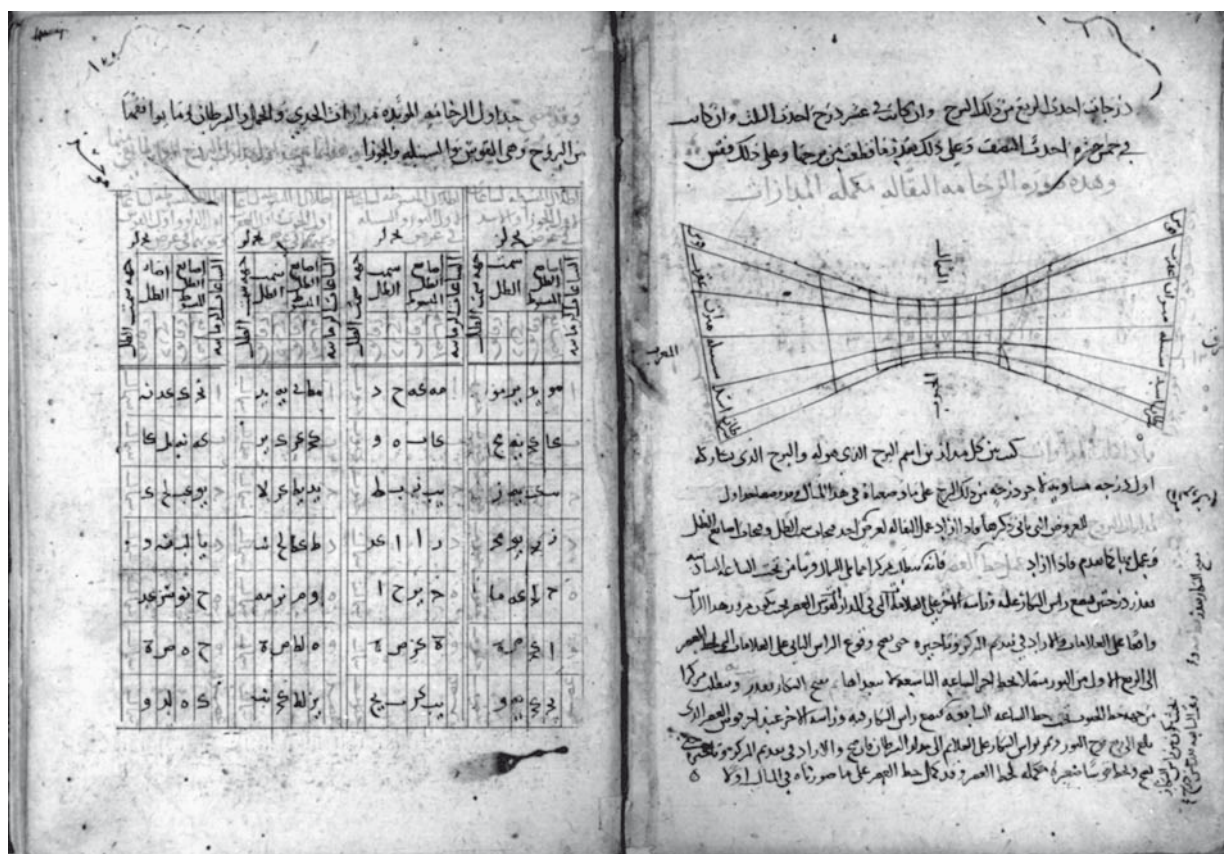



Fig. 7.1.3: Tables of radial coordinates (solar azimuth and shadow length) for marking the points of intersection of the seasonal hour lines with the equinoctial and solstitial shadow-traces on a sundial for altitude 13;37°, Taiz, as found in the treatise on the construction of the astrolabe, sundial and magnetic compass by the late-13th-century Yemeni prince al-Ashraf. [From MS Cairo TR 105, fols. 99v-100r, courtesy of the Egyptian National Library.]

horizontal and vertical sundials. Most of these developments appear to date from the 9th or 10th centuries, although the universal inclined sundial first appears in 14th-century Damascus, a couple of centuries before it was conceived, independently (?), in Europe.

For an overview of Islamic sundials and sundial theory see my article "Mizwala" in *EI*$_2$, repr. in King, *Studies*, C-VIII, and my chapter "Gnomonics" in *EHAS*. On Islamic sundial theory see Garbers, "Thābit b. Qurra über Sonnenuhren"; Luckey, "Thābit ibn Qurra über die Sonnenuhren", also Morelon, *Thābit ibn Qurra*, pp. 130-168; Luckey, *Ibrāhīm ibn Sinān über die Sonnenuhren*, (dissertation, Tübingen, 1944), new version edited by Jan P. Hogendijk in *IMA*, vol. 101 (1999). On the theory behind the markings for the seasonal hours see now Hogendijk, "Seasonal Hour Lines on Astrolabes and Sundials". The writings of al-Marrākushī are surveyed in Schoy, *Gnomonik der Araber*; see also *idem*, *Schattentafeln*, and *idem*, "Sonnenuhren der spätarabischen Astronomie". An important Maghribi treatise is available in a model study by Carandell, *Ibn al-Raqqām sobre los cuadrantes solares*. On the tables for sundial construction attributed to al-Khwārizmī, actually probably by Ḥabash, see King, "al-Khwārizmī", pp. 17-22, Rosenfeld *et al*., eds., *al-Khorezmi* (in Russian), pp. 221-234, and King,

Fig. 7.1.4: Tables of orthogonal coordinates (horizontal and vertical distance from the base of the gnomon) for constructing a vertical sundial at any inclination (here 15°) to the meridian for the latitude of Cairo (30°), as found in the treatise on sundial theory of the Egyptian astronomer al-Maqsī *ca*. 1275. [From MS Cairo DM 103, fols. 68v-69r, courtesy of the Egyptian National Library.]

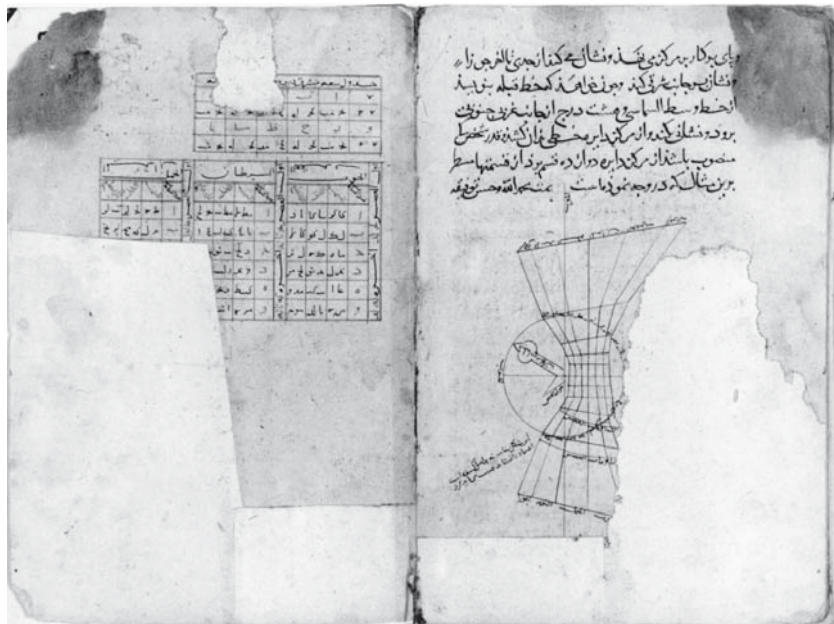



Fig. 7.1.5 Tables of radial coordinates with a diagram of a horizontal sundial for Isfahan appended to a 13th- or 14th-century copy of al-Bīrūnī's treatise on astrolabe construction. There are curves for the beginning and end of the *ʿaṣr*, as well as an indicator for the qibla at Isfahan. No such sundials are known to have survived from medieval Iran. See further King, *Mecca-Centred World-Maps*, pp. 300-301. The same qibla value 38° W. of S. for Isfahan is found on an astrolabe from *ca*. 1100: see **Fig. XIIIc-11b**. [MS Leiden UB Or. 123B, fols. 30v-31r, courtesy of the Universiteitsbibliotheek.]

Mecca-Centred World-Maps, pp. 349-350. On these and other Islamic tables for sundial construction see King & Samsó, "Islamic Astronomical Handbooks and Tables", pp. 92-94. A survey of such tables would be a useful contribution.

7.2 Some surviving Islamic sundials

Few Islamic sundials survive from the pre-Ottoman period, but each one has its own story to tell when it is analyzed in detail. The oldest surviving sundial dates from *ca*. 1000 and is signed by the Andalusī astronomer Aḥmad ibn al-Ṣaffār—see **Fig. 7.2.1**. Engraved on marble and alas broken, it bears markings for the seasonal hours and a part of a curve for the *ʿaṣr* (presumably there was also originally a curve for the *ẓuhr*). The segments for the seasonal hours are carelessly constructed. On a later Andalusī sundial of the same kind the markings are not much better—see **Fig. 7.2.2**, and on one Andalusī piece the markings are a disaster—see **Fig. 7.2.3**. On a sundial made for the Mosque of Ibn Ṭūlūn in Cairo in 696 H [= 1296-97] the curve for the *ʿaṣr* was incorrectly engraved and then altered unsatisfactorily: this may explain why it was broken into pieces—see **Fig. 7.2.4**. A 14th-century Egyptian sundial is constructed with the two halves, each with their own gnomon, superposed one on top of the other to save marble; here the curve for the *ʿaṣr* is carefully engraved—see **Fig. 7.2.5**.

A particularly interesting specimen made in Tunis in the 14th century displays only curves for four times of day with religious significance—see **Fig. 7.2.6**. Analysis of this sundial has not only shed light on contemporary religious practice in Tunis, but has also provided the key to an understanding of the reason why the daytime prayers are defined in terms of shadow increases. This in turn has led to a new understanding of the early development of the institution of prayer in Islam: in brief, the definitions of the *ẓuhr* and *ʿaṣr* in terms of shadow increases which became standard after the 9th century were conceived in order to relate the times of the prayers to the seasonal hours (see further **IV-5.2**). However, the original association of the prayers with the actual seasonal hours did not entirely disappear: the evidence for this is a small vertical sundial from 12th-century Syria on which the times of the prayers are related to the seasonal hours (**Figs. IV-7.4** and **XIVb-1**).

A magnificent sundial made in Damascus in the 14th century to adorn the main minaret of the Umayyad Mosque—see **Fig. XIVb-8**—displays time with respect to sunrise, midday and sunset, as well as with respect to the time of the afternoon prayer and even with respect to daybreak and nightfall. It is the most sophisticated sundial known from the medieval period, and although Ibn al-Shāṭir is not known to have written a treatise on it, a sundial of comparable complexity is discussed and illustrated by Najm al-Dīn al-Miṣrī, who identifies for it some 37 uses—see **Fig. 7.2.8**.

Such sundials have sadly been much neglected by historians of science, so that, for example, the spectacular Damascus sundial was published for the first time only about 30 years ago. The influence of any of this activity on European gnomonics has yet to be investigated, but at least one Islamic treatise on the simplest form of horizontal sundial for the seasonal hours came to be known in Europe through the 13th-century *Libros del saber*. An imposing but hapless azimuthal sundial purporting to be universal, which is described by the Andalusī Ibn Khalaf al-Murādī (*ca*. 1300), is also known from early Latin sources (Ripoll, *ca*. 1000).

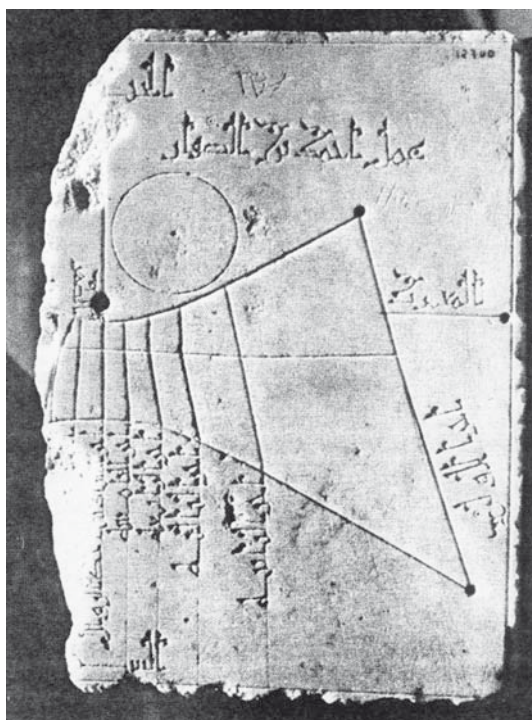



Fig. 7.2.1: The earliest surviving Islamic sundial, made by the astronomer Aḥmad ibn al-Ṣaffār in Cordova *ca*. 1000 (#7301). The hour-curves for the morning are intact, but carelessy constructed, some showing kinks at the euinoctial shadow trace. The markings for the afternoon are broken but one can still see the curve for the *ẓuhr*. [Courtesy of the Museo Arqueológico, Cordova.]

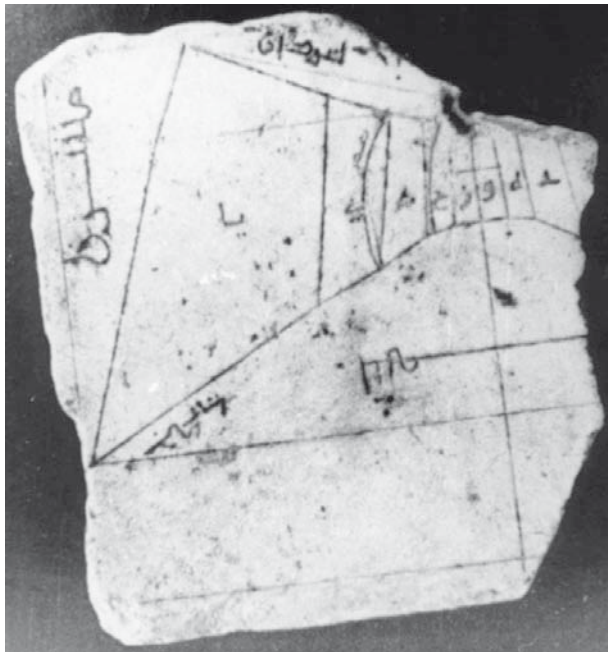



Fig. 7.2.2: An Andalusī sundial of uncertain date (11th-13th centuries?) (#7303) also showing lines for the seasonal hours and curves for the *ẓuhr* and *ʿaṣr*. [Courtesy of the Museo Arqueológico, Almeria.]

Fig. 7.2.3: A wretched sundial from al-Andalus (#7308), on which the markings correspond only vaguely to what they should. It is not clear why anyone would make a sundial like this from which the error in the time might be in hours, rather than minutes. The piece is clearly in the same Andalusī/Maghribī tradition as the 14th-century Tunisian sundial (see **Fig. 7.2.6**) on which the solstitial curves are approximated by arcs of circles, but here the maker has lost control of himself. [Original in the Museo Alhambra, Granada, illustration from King, "Andalusī Sundials", A, pl. 4.]

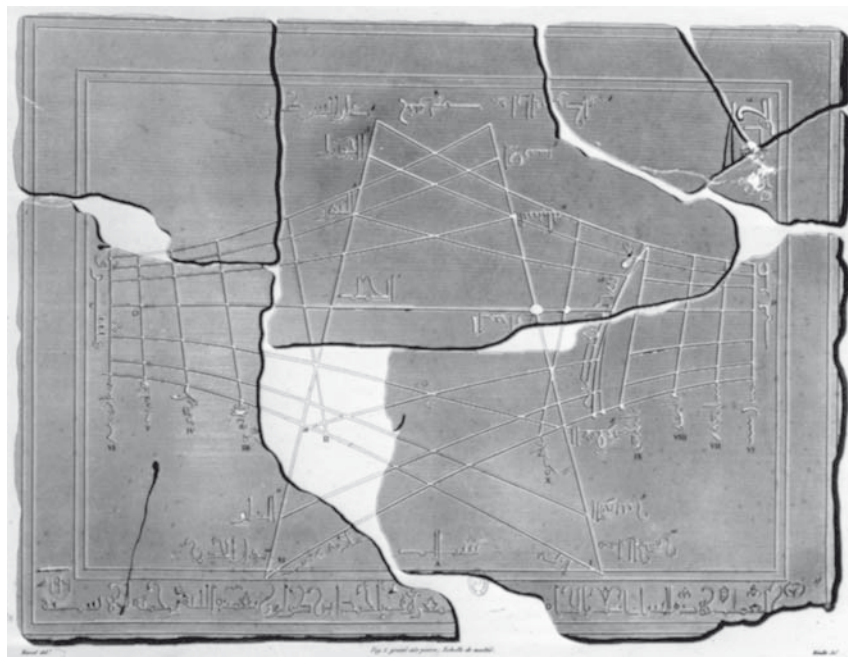



Fig. 7.2.4: This sundial from the late 13th century (#7316) was broken and hidden inside a column in the mosque courtyard, only to be rediscovered and reassembled by the scholars of Napoleon; the pieces then disapppeared mysteriously but fortunately not before a careful drawing of it had been prepared, later published in the *Description de l'Égypte* (1809-26). [From Janin & King, "Cadran solaire d'Ibn Ṭūlūn", pl. 1.]

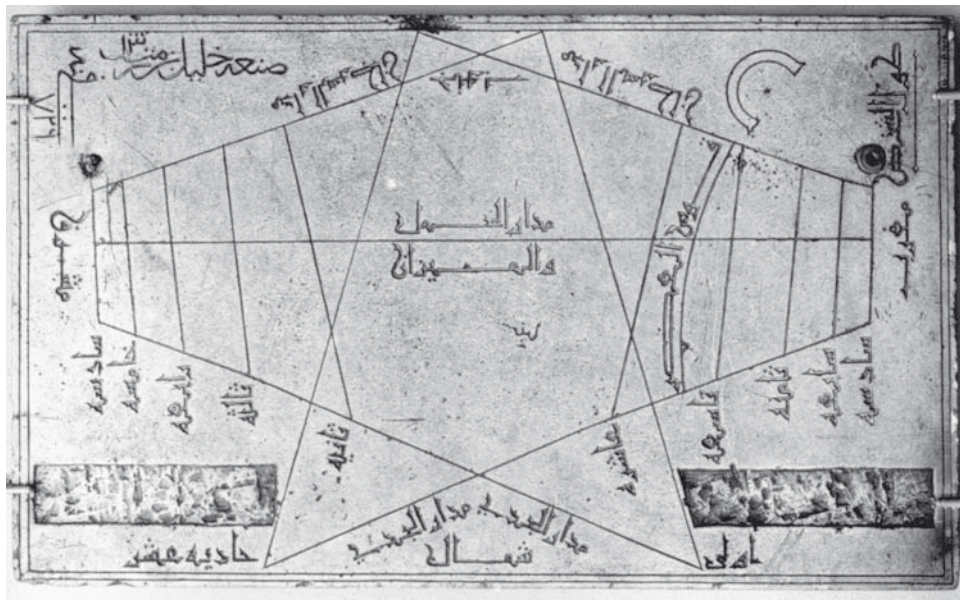



Fig. 7.2.5: A horizontal sundial made in Cairo in 726 H [= 1325/26] by Khalīl ibn Ramtāsh (#7317). The two halves of the sundial have been superposed, doubtless because marble was expensive, and the meridians and gnomon-holes for each half are at the sides. Such sundials are described in contemporaneous Mamluk treatises on gnomonics. The curve for the ʿ*aṣr* is clearly marked on the half serving the afternoon, and the qibla at Cairo is indicated by the semi-circular "*miḥrāb*" nearby. The latter indicates a direction of 34° S. of E. (not attested elswhere) rather than the usual 37° accepted by Mamluk astronomers. Instead of the hyperbolae usual for the solstitial traces we find rectilinear segments joining the extremities of the first/last hour with the midday shadows, that is, outside the domain of the shadows. Both gnomons are lost, but their length is indicated by a straight line in the corner near the *miḥrāb*. What was surely a dedicatory inscription has been deliberately effaced. [Courtesy of The Victoria and Albert Museum, London.]

Fig. 7.2.6: A sundial for Tunis made by Abu ʿl-Qāsim ibn Ḥasan al-Shaddād in 746 H [= 1345/46] (#7341). This is unique amongst surviving sundials for the special markings relating to a local tradition of determining a prayer at mid-morning (the *ḍuḥā*) and a time for preparation for the Friday service (the *taʾhīb*). [Courtesy of the late Alain Brieux, Paris.]

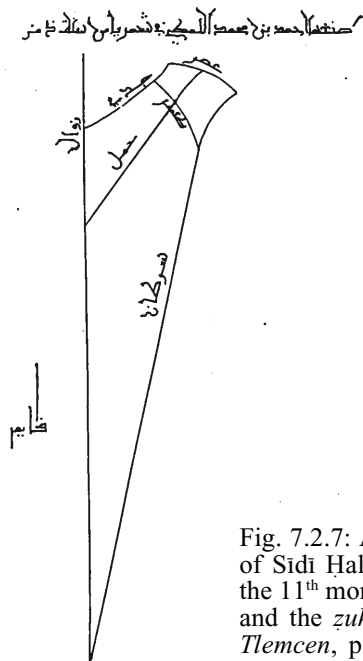



Fig. 7.2.7: A sketch of the cylindrical sundial on one of the columns in the Mosque of Sīdī Ḥalwī in Tlemcen (#7342) signed by Aḥmad ibn Muḥammad al-Lamṭī in the 11th month of 747 H [= Feb.-March, 1347]. It indicates only the times of midday and the *ẓuhr* and the *ʿaṣr*. From Marçais *père et fils*, *Les monuments arabes de Tlemcen*, p. 291.]

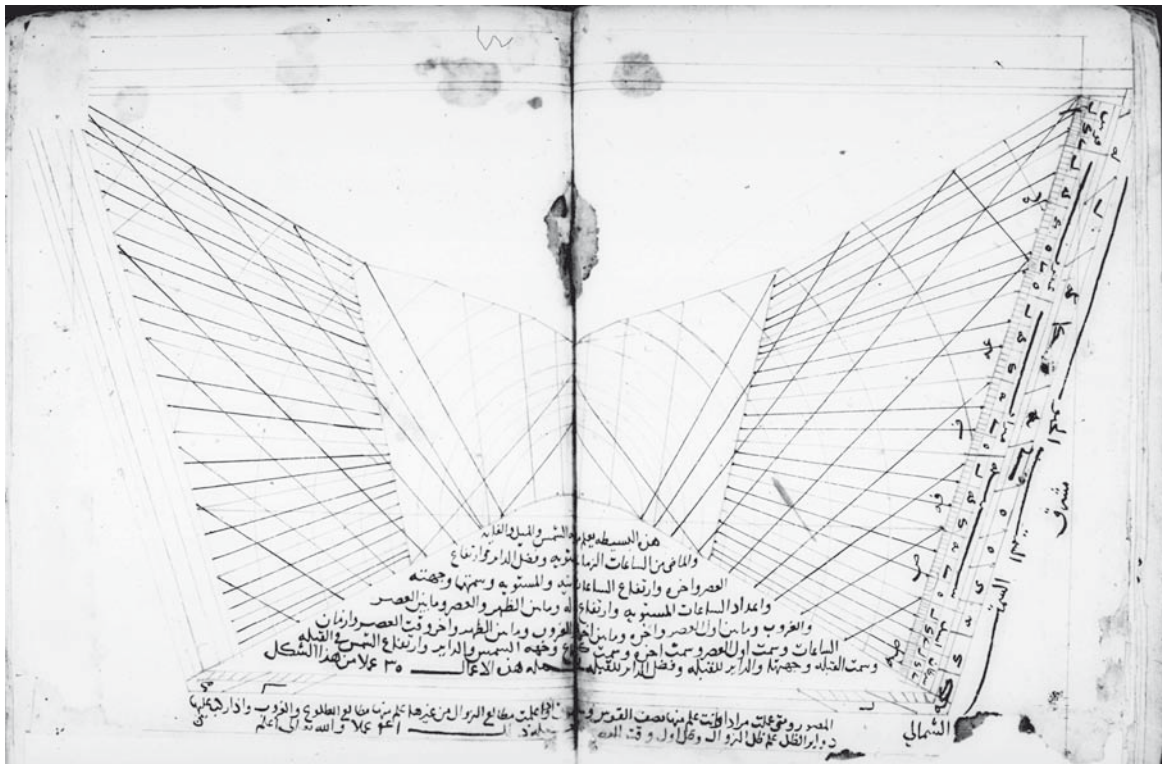



Fig. 7.2.8: A sketch of a horizontal sundial for latitude 36° in the treatise of Najm al-Dīn al-Miṣrī. He states that the markings can be used to solve 37 different problems, which he enumerates. The instrument is almost as complex as the splendid sundial of Ibn al-Shāṭir (see **Fig. XIVb-8**). [From MS Dublin CB 102,2, fols. 32v-33r, courtesy of the Chester Beatty Library.]

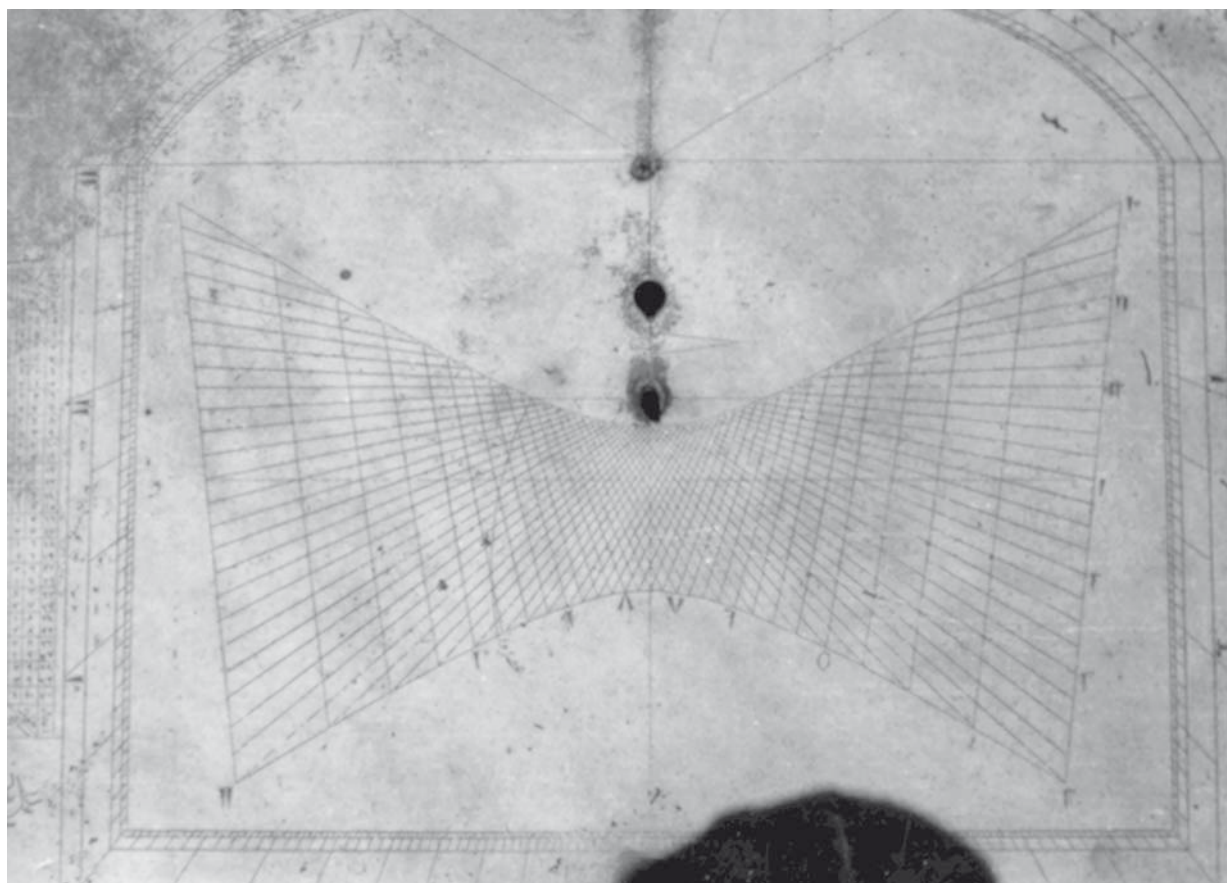



Fig. 7.2.9: The horizontal sundial (#7353) in the garden of the Topkapı Seray constructed during the reign of the Ottoman sultan Mehmet Khān, that is, *ca*. 1475, and renovated by ʿAbdallāh Silaḥdār in 1208 H [= 1793/94]. For details see Meyer, *Istanbul Sundials* (in Turkish), pp. 65-71. The length of the rectangular marble slab is just less than a metre. The markings serve the seasonal hours of daylight and the equinoctial hours from sunrise and before sunset. [Photo kindly provided by the late Wolfgang Meyer, Istanbul.]

Fig. 7.2.10: Of these two sundials (#7510) on the south wall of the Cathedral in Regensburg, the lower one, dated 1487 in Gothic numerals, is perhaps the most sophisticated sundial surviving from medieval Europe. It is a serious sundial for the equinoctial hours, showing hyperbolic shadow-traces (albeit a bit wobbly in places) for each zodiacal sign. For some reason, someone added a less sophisticated sundial with a polar gnomon, with the hours marked in Roman numerals. This second sundial is dated 1509, the year being engraved in Renaissance numerals. [Photo by the author. On the numerals see King, *The Ciphers of the Monks*, p. 288.]

Studies of individual sundials and groups thereof include the following. On the sundial used by the Caliph ʿUmar II to regulate the prayer times see **IV-7.1**. Extant Andalusī sundials are presented in King, "Three Sundials from al-Andalus", and my chapter "Los cuadrantes solares andalusíes", in *Madrid MAN 1992 Exhibition Catalogue*, pp. 89-102, with new materials in Labarta & Barcelo, "Ocho relojes de sol hispanomusulmanes", and *eædem*, "Un nuevo fragmento de reloj de sol andalusí". al-Murādī's universal azimuthal sundial (at first sight of the same type as the *musātara* of al-Marrākushī described in Janin, "Projection horizontale", and Charette, *Mamluk Instrumentation*, pp. 166-170), was first mentioned in King, "Medieval Mechanical Devices", in *Studies*, XV, p. 289, and *idem*, "Three Andalusī Sundials", p. 368. It has now been studied in detail in Casulleras, "Andalusī Sundial"; Charette labels it "extremely crude, if not absurd". A very crude sundial of sorts (horizontal, with radial markings for each 15°), which is described in several medieval sources, Arabic, Hebrew and Latin, is discussed in King, "Three Andalusī Sundials", pp. 367-368, and now Zenner, "Sonnenuhr des Gerbert". The most spectacular sundial of the Middle Ages, that of Ibn al-Shāṭir, is described in Janin, "Cadran solaire de Damas", and in *Paris IMA 1993-94 Exhibition Catalogue*, p. 439, no. 334—see now **XIVb-8**. Various other sundials in Cairo and Jerusalem are described in Janin & King, "Cadran solaire d'Ibn Ṭūlūn", and King & Walls, "Jerusalem Sundial". Michel & Ben-Eli, "Un cadran solaire polaire", describes the Ottoman polar sundial in Acre. The important sundial featuring only the prayer-times is described in King, "Tunisian Sundial"—see now **IV-5.2**. Some other Maghribi sundials are featured in Janin, "Gnomonique tunisienne". On Ottoman sundials see also Ünver, "Cadrans solaires en Turquie"; Meyer, "Istanbul Sundials", both superseded by *idem*, *Istanbul Sundials* (in Turkish). A few portable sundials have been published: a Syrian vertical dial is described in Casanova, "Cadran solaire syrien", also *Paris IMA 1993-94 Exhibition Catalogue*, pp. 436-437, no. 332—see now **IV-7.4** and **XIVb-1**. A Turkish dial is described in Naffah, "Cadran cylindrique ottoman". Livingston, "Islamic Conical Sundial", is based on textual sources. Some individual Islamic sundials of particular sophistication have attracted the attention of sundial buffs: see, for example, Ferrari & Severino, *Meridiane islamiche*, (privately distributed); and de Vries *et al*., "Hafîr and Halazûn". These sundial specialists will find yet more interesting sundials in Charette, *Mamluk Instrumentation*.

CHAPTER 8

EQUATORIA

An equatorium is a mechanical device for finding the position of the sun, moon and planets without calculation, using instead what is essentially a geometric model to represent the celestial body's mean and anomalistic motion. To use Ptolemy's models for this purpose, one simply takes the values of the mean longitude and the anomaly from the mean-motion tables standard in the astronomical handbooks and feeds these into the instrument, which then displays the true position of the celestial body. It is known that already Archimedes had a complicated equatorium, and, of course, the Antikythera device from *ca*. 80 B.C. with highly complex gearing to reproduce the relative motions of the sun and moon represents the pinnacle of Greek mechanical engineering. We have already mentioned al-Bīrūnī's solar-lunar mechanism inside an astrolabe (**5.4**). Furthermore, we have at least four treatises on the equatorium, the first three being by Andalusi astronomers and dating from the period 1015-1115: see **Fig. 8.1**. Alas, no medieval Islamic equatoria or planetaria survive, although the "astrolabic *zīj*" of Hibatallāh (**5.3**), the sole copy of the *Zīj al-ṣafāʾiḥ* of the 10th-century Baghdad scholar Abū Jaʿfar al-Khāzin, shows evidence of having been fitted with a series of circular plates to serve as an equatorium of the kind known from the treatise of the Andalusī scholar Abu ʻl-Ṣalt (*ca*. 1100). Whilst the latter was an Andalusī production, there can be no doubt that it was in an Abbasid ʿIrāqī tradition. Considerably more sophisticated was the equatorium described by al-Kāshī in the early 15th century, which could be used even to determine planetary latitudes: see **Fig. 8.2**. We have already mentioned the planetarium given by the Ayyubid Sultan al-Ashraf to the Emperor Frederick II (**4.12**).

In 1966, Emmanuel Poulle cited a 15th-century European report that the instrument known as the sexagenarium was of contemporaneous Egyptian provenance. The sexagenarium is a quadrant with a trigonometric grid on one side, and a series of circular scales for computing mean longitudes and anomalies for the sun, moon, and planets on the other. The trigonometric quadrant serves not only to provide numerical solutions to problems of spherical astronomy but also to compute equations of the sun, moon, and planets. (The latter function serves only to challenge the wits of the user, because auxiliary tables for computing the equations obviate the need for such tedious calculations.) While the trigonometric quadrant and associated instructions for performing computations in spherical astronomy were well-known in 15th-century Cairo, no such planetary dials are known from there. No trigonometric quadrant is mentioned by al-Kāshī, and in any case his equatorium renders such a device superfluous.

In 2003, it became clear that a treatise in 20 chapters by Jamāl al-Dīn al-Māridīnī (Cairo, *ca*. 1425?) was the source for a Valencian translation of 1463, shortly thereafter translated into Latin. The translator had seen such an instrument shown to him in Valencia by a *mudéjar* from Paternia in 1450. He was aware of the existence of other Arabic works on the instrument in

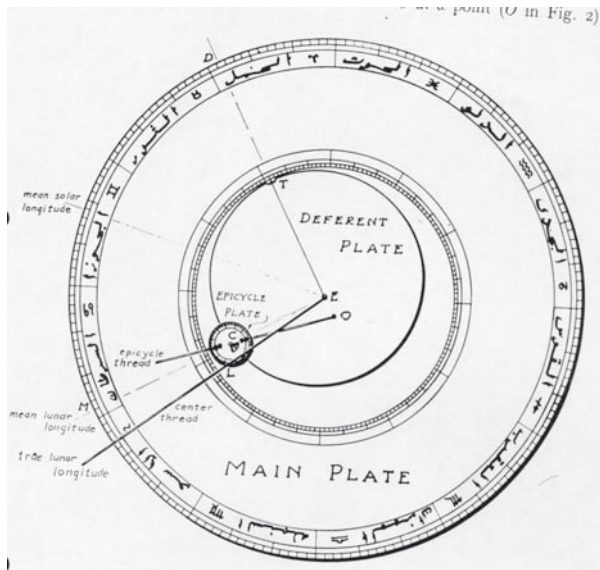



Fig. 8.1: E. S. Kennedy's reconstruction of the plates for Saturn in the equatorium of Abu 'l-Ṣalt. [From Kennedy, "The Equatorium of Abū al-Ṣalt", p. 76.]

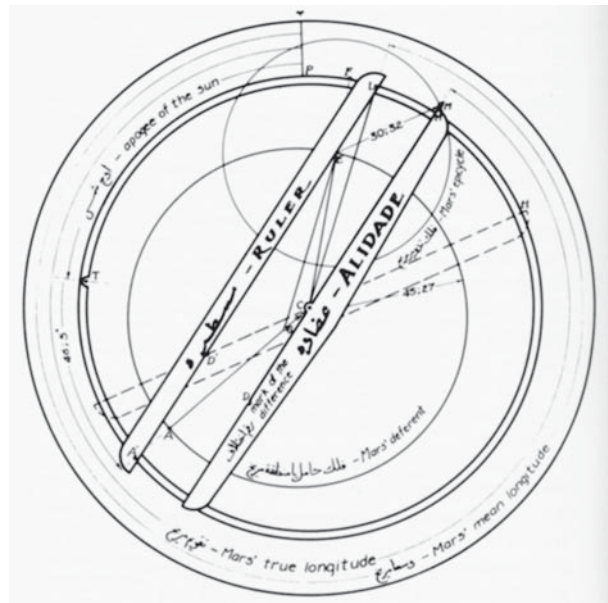



Fig. 8.2: E. S. Kennedy's reconstruction of the procedure for finding the true longitude of Mars using al-Kāshī's equatorium. [From Kennedy, *al-Kāshī's Equatorium*, p. 194.]

100 and 60 chapters, although it is not clear that he had access to them. In any case, he translated a concise treatise in 20 chapters.

On Andalusī equatoria in general see Comes, *Ecuatorios andalusíes*; and *eadem*, "Los ecuatorios andalusíes". Specific studies include Millàs Vallicrosa, *Azarquiel*, pp. 425-455; Kennedy, "The Equatorium of Abū al-Ṣalt"; Samsó, "Ecuatorio de Ibn al-Samḥ", and Millás Vendrell, "Apogeos planetarios en el ecuatorio de Azarquiel". On the astrolabic *zīj* of al-Khāzin fitted with an equatorium see King, "*Zīj al-Ṣafā'iḥ*", esp. pp. 111-112; and Samsó, "al-Bīrūnī in al-Andalus", esp. pp. 594-601 and 611-612. On al-Kāshī's instrument see Kennedy, *al-Kāshī's Equatorium*, and various articles thereon repr. in *idem et al.*, *Studies*, pp. 448-480. On the equatorium in medieval Europe see Poulle, *Équatoires médiévaux*.

On the sexagenarium see Poulle, "Sexagenarium", esp. p. 130, and now Aguiar & Marrero, *Sexagenarium*, on a treatise on the instrument from 15th-century Valencia, translated from an Arabic original, for which see *Cairo ENL Catalogue*, II, pp. 485-486. On Jamāl al-Dīn al-Māridīnī see *Cairo ENL Survey*, no. C47.

CHAPTER 9

MISCELLANEOUS INSTRUMENTS

9.1 Universal instruments for timekeeping by day and night

Ḥabash al-Ḥāsib invented an ingenious instrument for timekeeping for any latitude by *the stars*, which is still not completely understood: on this see **XIIb-12**. I have attempted to show that the universal horary dial on the medieval English *navicula*, which serves timekeeping for any latitude by *the sun*, is also of 9th-century Baghdad provenance: see **XIIb-14**. Both of these instruments seem to have been forgotten in later Islamic astronomy, although the unique 13th-century manuscript of Ḥabash's treatise on the stellar device shows signs of abuse at the hands of a series of copyists. (The same is true of the unique surviving copy of his treatise on the melon astrolabe.)

A word on the medieval European instrument known as the nocturnal or nocturlabe, for simple timekeeping at night throughout the year by the stars of the Great Bear, is appropriate here. This is not attested in any known Arabic textual sources, and few very late Islamic examples survive. The device seems to have developed independently in medieval Europe, in a milieu where the far superior astrolabe was not yet fully appreciated. In Europe it gained considerable popularity, and the late Islamic examples display European influence.

On Ḥabash's universal instrument from reckoning time from stellar altitudes see King, *Mecca-Centred World-Maps*, pp. 354-358, and now Charette & Schmidl, "Ḥabash's Universal Plate", for the text and an annotated translation. On the *modus operandi* see now **XIIb-12**. On the *navicula* see, for example, Brusa, "Le navicelle orarie di Venezia", and for some first wild hypotheses about its possible connection with Ḥabash, see King, *Mecca-Centred World-Maps*, pp. 351-359. See now **XIIb**.

On the nocturnal see Samsó, "Medición del tiempo en al-Andalus *ca*. 1000", pp. 83-85, and Oestmann, "History of the Nocturnal".

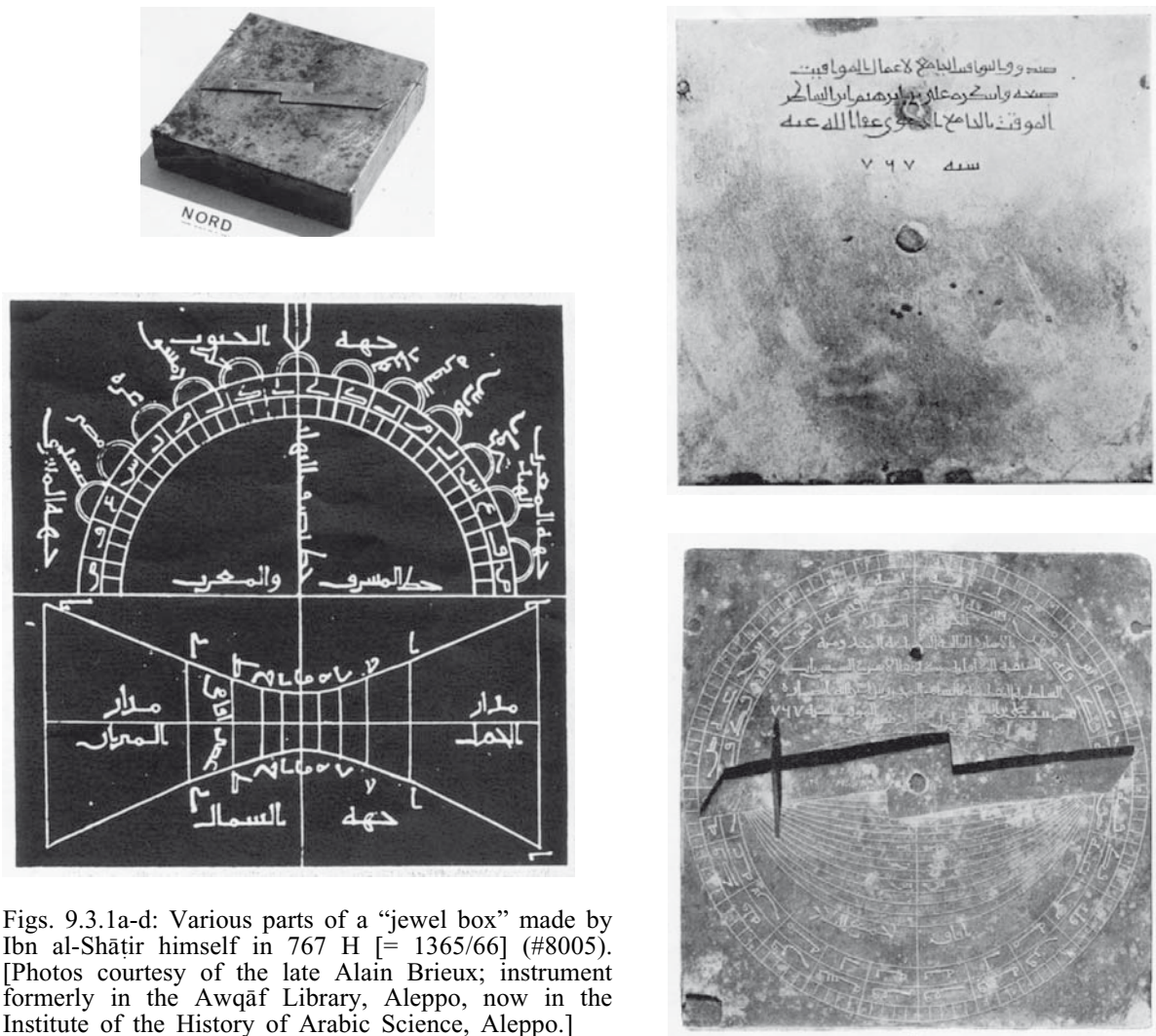
9.2 The magnetic compass

The earliest reference to the magnetic compass in the astronomical literature occurs in a treatise compiled in the Yemen at the end of the 13th century (**Fig. 9.2.1**). Here, however, the author, none other than the Yemeni Sultan al-Ashraf, makes no claim to be the first to write on the compass, and it is certain that he was not. The device he describes is a bowl in which the needle floats on a liquid. In an Egyptian treatise on spherical astronomy from *ca*. 1300, the author, Ibn Samʿūn, describes a "dry" compass-bowl. From various 13th-century sources, we know that the compass was in widespread use amongst the navigators of the eastern Mediterranean at that time. A ceramic compass-bowl made in Damascus *ca*. 1518 has been preserved for us; the data on it—names of 40 localities and their qibla-values to the nearest degree—is from an Iranian tradition two, if not three, centuries earlier: see further **XIVd-9**.

Fig. 9.2.1: The compass bowl described and illustrated in the treatise of the Yemeni ruler al-Ashraf *ca*. 1295. [From MS Cairo TR 105, fol. 145v, courtesy of the Egyptian National Library.]

On the compass in the Islamic Near East see Wiedemann, "Zur Geschichte des Kompasses bei den Arabern"; Tibbetts, *Arab Navigation*, pp. 290-294; King, *Astronomy in Yemen*, II-8.2; and *Cairo ENL Survey*, pl. LXIV; Schmidl, "Two Early Arabic Sources on the Magnetic Compass"; King, *Mecca-Centred World-Maps*, pp. 107-115, *etc*.; and the survey article "Ṭāsa" in EI_2. On the ceramic compass-bowl see King, *op. cit*., pp. 110-114, 168-170, and 478-480, and now **XIVb-9**.

9.3 Astronomical compendia

During the 14th and 15th centuries, Muslim astronomers developed compendia, devices performing several different functions. In Damascus in the mid 14th century Ibn al-Shāṭir devised a compendium in the form of a box, the lid of which could be raised to serve the astronomical function of the box and its paraphernalia for any of a series of terrestrial latitudes. This lid bears a set of astrolabic horizon markings, and a removable plate inside the box bears a universal polar sundial and a set of qibla-markers for different localities. All of the other parts of this compendium, which are missing

Figs. 9.3.1a-d: Various parts of a "jewel box" made by Ibn al-Shāṭir himself in 767 H [= 1365/66] (#8005). [Photos courtesy of the late Alain Brieux; instrument formerly in the Awqāf Library, Aleppo, now in the Institute of the History of Arabic Science, Aleppo.]

from the only surviving specimen of it now preserved in Aleppo, such as a magnetic compass for aligning the instrument in the cardinal directions and the sights for reading the time from an equatorial scale on the lid of the box, are described in a treatise on its use, authored by Ibn al-Shāṭir himself and partially extant in a unique manuscript now preserved in Berlin (**Figs. 9.3.1-3**).

The fact that the compass-needle may deviate from the meridian by a certain number of degrees was first recorded in the Islamic world by the 15th-century Egyptian astronomer al-Wafā'ī, who modified Ibn al-Shāṭir's instrument into a semi-circular equatorial dial with a sighting device, compass and qibla indicator, and also wrote a treatise on its use (see **Fig. 9.3.4** and also **Fig. VIb-14.1**). These Islamic compendia may have had some influence on later European dials and compendia of the same type; however, the astronomical ideas underlying these instruments are so simple that it is hardly necessary to anticipate transmission.

1866. a. On the philosophical instrument called Çandûq al-yawâqyt. m. 13 pp.

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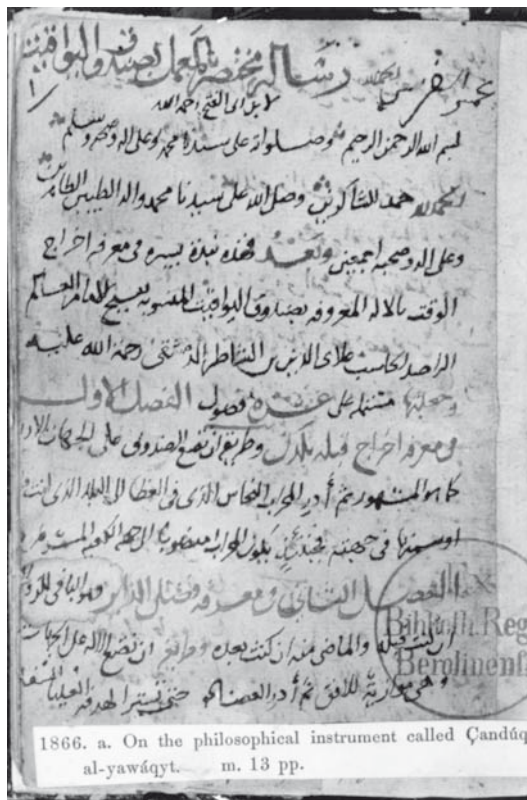
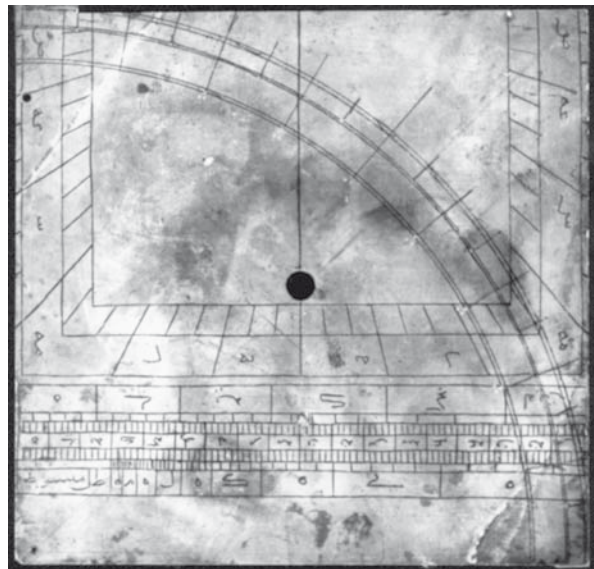
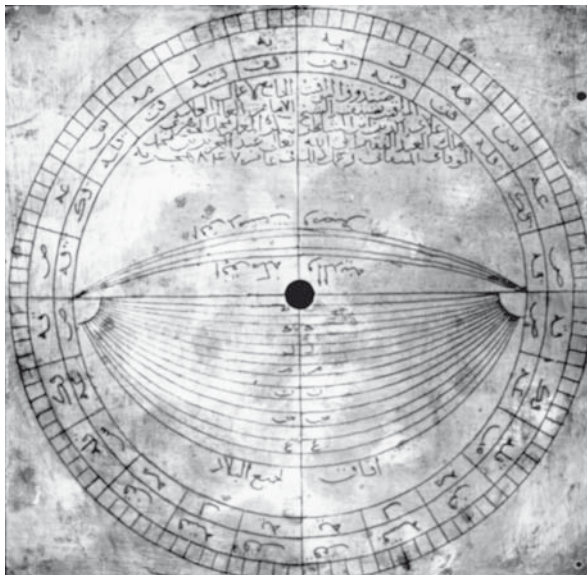


Fig. 9.3.2 The beginning of a treatise by the Egyptian astronomer Ibn Abi ʿl-Fatḥ al-Ṣūfī (*ca*. 1500) on the use of the "jewel box" of Ibn al-Shāṭir. This short treatise is complete and supplements the fragments of a more substantial treatise by Ibn al-Shāṭir himself found in the same manuscript. [From MS Berlin DSB Ahlwardt 5845, fol. 1r, courtesy of the Deutsche Staatsbibliothek (Preußischer Kulturbesitz).]

Figs. 9.3.3a-b: The sole remnant of a "jewel box" made by Muḥammad al-Jawharī for the Egyptian astronomer ʿIzz al-Dīn al-Wafāʾī in 847 H [= 1443/44] (#8006). The plate bears a series of horizons on one side and a shadow square and a vertical sundial on the other. [Photos courtesy of the late Professor Dr. Muammer Dizer, Kandilli Observatory.]

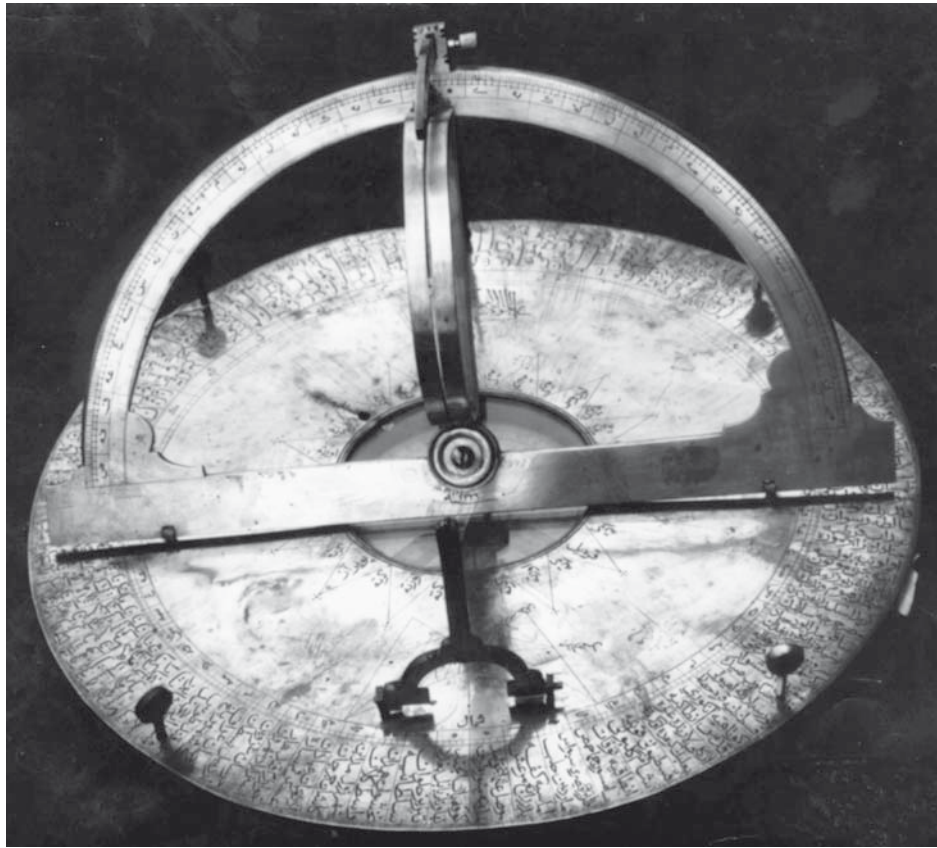



Fig. 9.3.4: An equatorial semi-circle signed by "ʿAlī *al-muwaqqit* Abu 'l-Fatḥ" and dated 1166 H [= 1752/53] (#8007). [Photo courtesy of the late Professor Dr. Muammer Dizer, Kandilli Observatory, who published this instrument in his "Equatorial Semicircle".]

On Islamic compendia see Janin & King, "Ibn al-Shāṭir's Compendium"; Tekeli, "Equatorial Semicircle"; Brice & Imber & Lorch, "Equatorial Semicircle", reviewed in King, *Studies*, B-XIII; Dizer, "Equatorial Semicircle"; and F. R. Maddison in *London Khalili Collection Catalogue*, I, pp. 278-279, nos. 168-169. A splendid study of European compendia is Gouk, *Ivory Sundials of Nuremberg*, in which Ibn al-Shāṭir's compendium is mentioned on p. 17.

9.4 Qibla-indicators

The compendia of Ibn al-Shāṭir and al-Wafāʾī bore markings similar to those found on various Iranian astrolabes from the 11th to 16th centuries that enabled one to find the qibla or local direction of Mecca in various localities. Simplistic maps of the world centred on Mecca, specifically intended for finding the qibla approximately, were also available. In later centuries, qibla-indicators consisting of a compass and a gazetteer of qibla values for major cities were in widespread use. Alternatively, these instruments might have a circular base fitted with a compass and a horizontal sundial, with

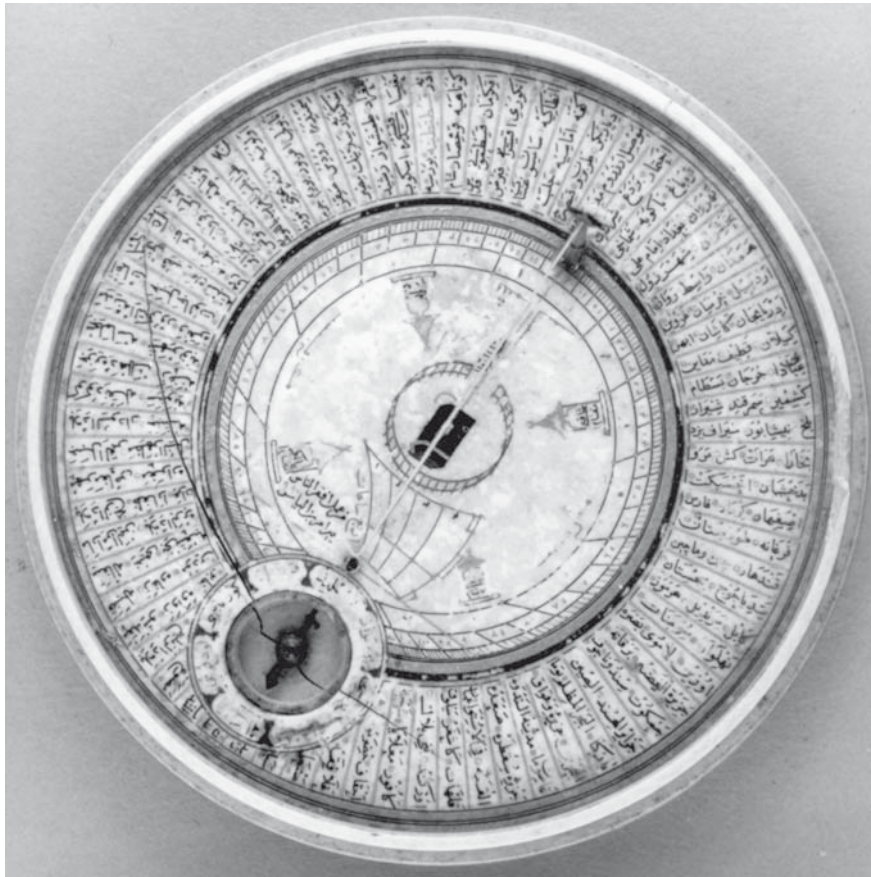



Fig. 9.4.1: A simple qibla-indicator from *ca*. 1600 (#8060), on which the names of various localities are arranged around a horizontal circular scale. But the qibla directions used here were not calculated according to formulae available since the 9th century, rather they were estimated by traditional methods. See further King, *Mecca-Centred World Maps*, pp. 115-117. [Courtesy of the British Museum, London.]

localities marked all around the circumference. The underlying qiblas were not part of the mathematical tradition, that is, they were unrelated to the values in the gazetteers; rather, they were in the folk astronomical tradition of sacred geography.

For a survey of several qibla-indicators of different kinds (and the underlying geographical notions) see King, *Mecca-Centred World-Maps*, pp. 107-123. For a detailed study of one Ottoman piece see Chidyaq, "Indicateur de qibla". For several such late instruments, see now Stautz, "Max von Oppenheim's Instrumente", A-B.

9.5 Mecca-centred world-maps

Three world-maps engraved on brass plates survive from the late 17th century; they were probably made in Isfahan—see **Figs. 9.5.1** and **VIa-18.1**. The third came to light only in 2001—see **VIIc**. They are centred on Mecca and are fitted with a highly complex grid, which together with the

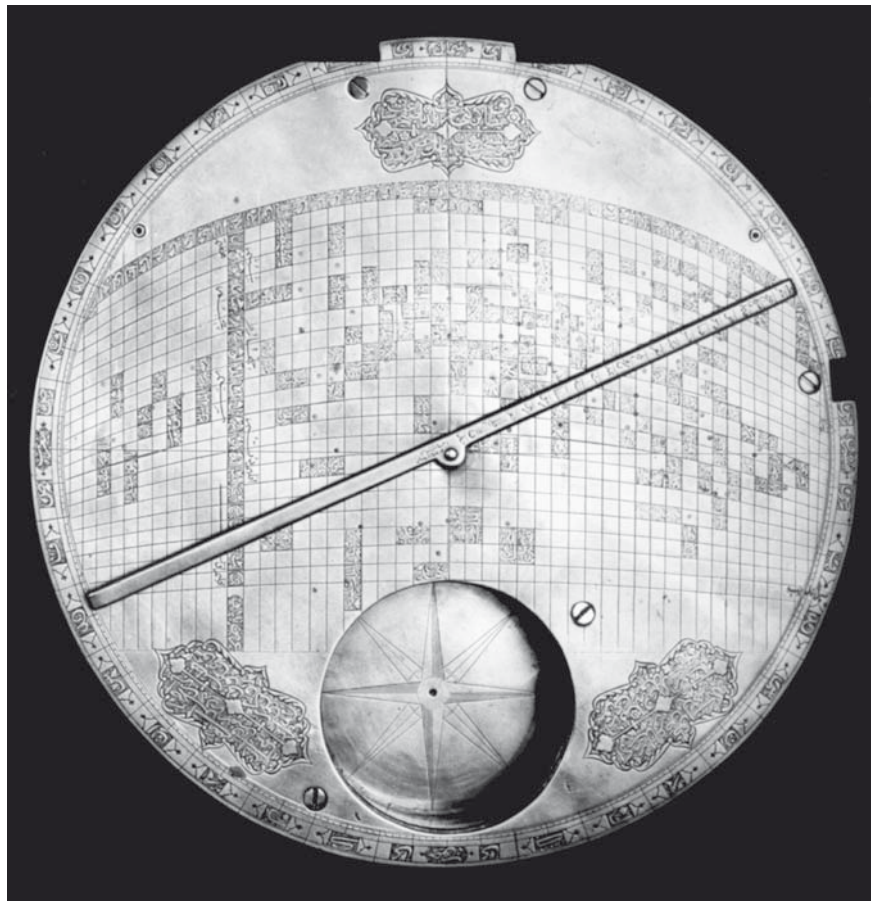
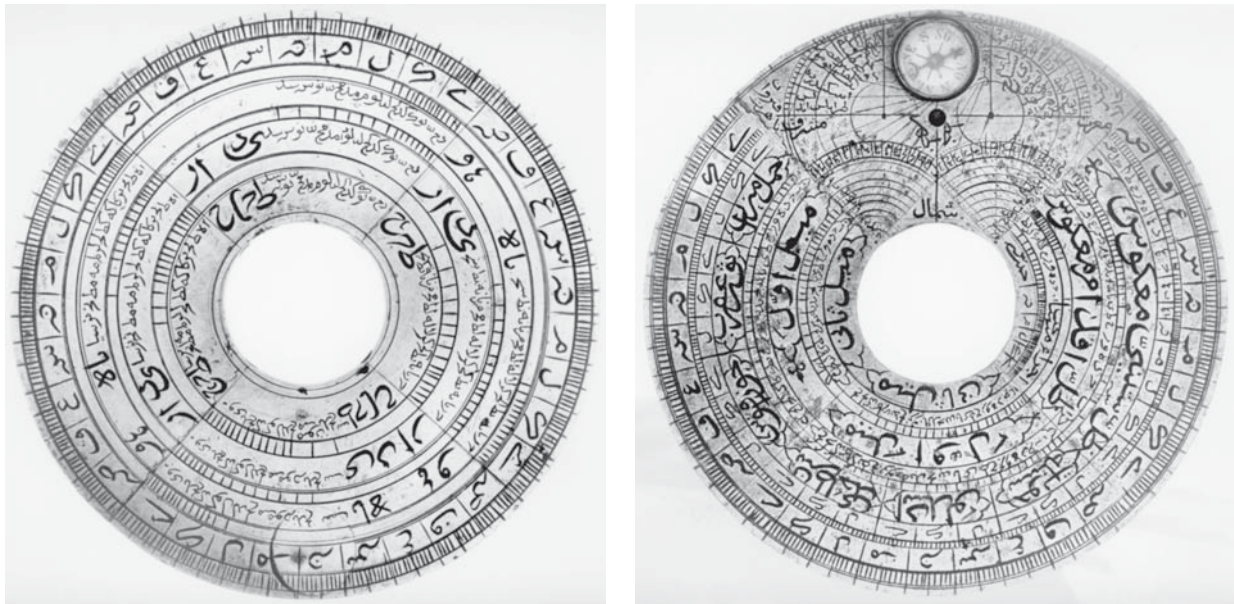



Fig. 9.5.1: A much more sophisticated qibla-indicator (#8024), apparently made in Isfahan *ca*. 1675. The cartographical grid centred on Mecca enables the user to find the qibla of any locality from Spain to China. One simply places the alidade on the stud representing the locality and reads off the qibla on the outer scale and the distance from Mecca along the scale. A modern equivalent to this type of grid was first described in the Western literature by the German historian of Islamic science Carl Schoy *ca*. 1920. [Photo by Christie's of London, courtesy of the new owner, the Dār al-Āthār al-Islāmiyya, Kuwait.]

diametrical rule enable the user to read off the qibla on the circumferential scale and the distance to Mecca in *farsakh*s on a non-uniform scale on the rule. The geographical data underlying the positions of the *ca*. 150 localities from al-Andalus to China, and from Europe to the Yemen, found on each map are taken from a table compiled near Samarqand in the early 15th century, but the mathematics underlying the grid and its construction is at once so sophisticated and yet—if one knows a formula relating the qibla to the distance derived by Muslim scholars in the 9th century—so simple that, in my opinion, it can only have been conceived in the most creative period of Islamic science. All of the maps appear to be copies of an earlier map of the same kind. Maps serving this purpose were first conceived in Europe in the first two decades of the 20th century, and the fact that such maps could have been made already in the 17th century (and before) results from the fact that it is the *sine* of the distance arc which underlies the non-uniform scale on the diametrical rule.

Although there is not a shred of tangible evidence, it would not surprise me if we were witness to a creation of one or other of the two (and only) Muslim scholars who were (a) deeply involved in solutions to the qibla problem, and (b) also concerned with mappings preserving direction and distance (though not the sine of the distance) to and from a central point. I refer on the one hand to al-Bīrūnī, who authored a dozen works on mathematical geography and cartography, of which only two have survived. The other candidate, more original than al-Bīrūnī in mathematical methods, was Ḥabash al-Ḥāsib, who developed the first accurate solutions to the qibla problem and also devised the "melon" astrolabe, based on a mapping which preserves direction and distance from and to the centre. (In the melon astrolabe the centre was the pole, and the mathematics is more complicated if the mapping is centred on a non-polar location.) Yet no texts relating to this remarkable tradition in mathematical cartography, or even a passing reference or a set of tables for constructing such grids, have been identified yet. However, Jan Hogendijk of Utrecht has discovered two texts—one from 10th-century Baghdad and the other from 11th-century Isfahan—in which the solution of the qibla problem by means of conic sections is mentioned. The first is by an author who knew the works of Ḥabash and who was known to al-Bīrūnī, and the second is by an author who elsewhere cites al-Bīrūnī. See further **VIIc**.

See King, *Mecca-Centred World-Maps*, on the first two world-maps, and **VIIc**, on the third world-map and on the materials discovered by Jan Hogendijk.

Figs. 9.6.1a-b: The two sides of a small annulus (#8093) engraved with scales, some more convincing than others. The object is from Iran and probably dates from *ca*. 1800, but was doubtless inspired by earlier models. On the front (a) we find scales for the first declination and, naïvely, also for second declination (there is no noticable difference), and for the cotangent to base 7 and 60 and the sine to base 60. In addition there are qibla-directions indicated next to the (European) compass. The two sine quadrants nearby are non-functional. With the scales on the back (b) the maker seems to have lost control of himself. Perhaps his model had some tables displaying right and oblique ascensions. Certainly he forgot to label the functions represented on this side of the annulus. [Courtesy of the Museum for the History of Science, Oxford.]

9.6 "Slide-rules" for astronomers

In the Middle Ages there was an instrument called *mīzān al-Fazārī* consisting of a set of scales and astronomical markings such as sundials and graphs on the sides of a rod of square cross-section: see **XI-6.4**. The scales served to find values of various functions of importance for the astronomer. It seems that the device goes back to the 8th-century astronomer al-Fazārī. A late Iranian device, now circular, serves the same purpose, bearing a multiplicity of scales of one sort or another but attesting to much wishful thinking on the part of the maker: see **Fig. 9.6.1**.

On the *mīzān al-Fazārī* see most recently Charette, *Mamluk Instrumentation*, pp. 147, 163-164 and 222, and the references there cited.

9.7 The pendulum

In the modern literature, and in dozens of Internet sites, one encounters the assertion that the 10th-century Egyptian astronomer Ibn Yūnus discovered the principle of the pendulum. Thus, for example, S. H. Nasr in his book *Islamic Science*:

> "Ibn Yūnus was also the first person to make a serious study of the oscillatory motion of a pendulum, which finally led to the invention of the mechanical clock."

However, there is not a trace of this in the known original sources relating either to Ibn Yūnus, or to any other medieval Muslim astronomer. (I write this not because I do not like Ibn Yūnus but because I have spent my academic life pursuing every lead to his works in libraries all over the world. As the reader of **I** and **II** will have noticed, he is the real hero of the first volume of this book dealing with astronomical timekeeping in Islamic civilization.) It is possible to trace the myth of Ibn Yūnus' association with the pendulum in the European literature from the 17th century onwards: it is one of those cases where someone thought that Ibn Yūnus *must* have had a pendulum because he made such accurate observations. In this case, it will be easier to find hitherto undiscovered source material than to kill the myth. Already Eilhard Wiedemann in the 1910s pointed to the diagrams in Islamic sources that *look as though they display a pendulum*; these in fact display a plumb-line: see **Fig. 9.7a**. The first pendula known in the Near East appear to have been those in European clocks presented to an Ottoman sultan in the late 17th century, but the subject of mechanical clocks does not concern us here. (See **5.4** on astrolabic clocks.)

On the pendulum myth see King, "Ibn Yūnus and the Pendulum", and the references to earlier studies by Eilhard Wiedemann, including his "Über die angebliche Verwending des Pendels bei den Arabern", A-B. On Nasr, *Islamic Science*, p. 101, see already King, "Review of Nasr, *Islamic Science*", A, pp. 217-218 / B, col. 342a. On this and various other myths associated with Ibn Yūnus—including his "well-equipped observatory" and his "discovery" of the prosthapheresis formula in trigonometry—see further King, "Astronomy in Fatimid Egypt", esp. pp. 507-509. On clocks in the Near East see Tekeli, "Ottoman Clocks"; Kurz, *European Clocks in the Near East*; and King, *Mecca-Centred World-Maps*, pp. 284-292.

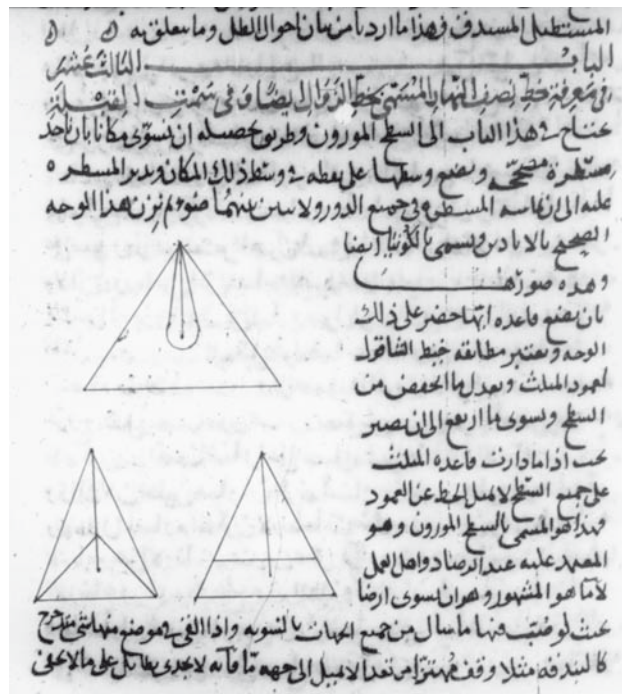



Fig. 9.7a: An illustration of a plumb-line in the treatise on the Indian circle, a simple geometric construction for determining the meridian as the bisector of the angle between the two azimuths of the sun in the morning and afternoon at times when it has the same altitude. Clearly the observations of the sun need to be made from a horizontal plane, hence the need for a plumb-line. Claims that Muslims used a pendulum for timekeeping are based on fantasy, not on any textual sources, let alone on such illustrations. This one is taken from a copy of the *Nihāyat al-idrāk*, a treatise on theoretical astronomy, by the 13th-century scholar Quṭb al-Dīn al-Shirāzī. [From MS Cairo Ṭalʿat *hayʾa* 45, fol. 145r, courtesy of the Egyptian National Library.]

CHAPTER 10

SCHOOLS OF INSTRUMENT-MAKERS

The most important contributions to instrumentation were made by individuals working alone. (Ibn Yūnus in the 10th century was of this opinion regarding astronomy in general.) As the leading lights in this field we may mention Ḥabash al-Ḥāsib and Ḥāmid ibn ʿAlī al-Wāsiṭī, both of Baghdad, the former in the 9th century and the latter in the 10th, and al-Khujandī, who worked in Rayy and Baghdad in the 10th century; ʿAlī ibn Khalaf and Ibn al-Zarqālluh from the 11th, both active in Toledo; and Ibn al-Sarrāj from the 14th, working in Aleppo. The most influential authors, on the other hand, were al-Bīrūnī in Central Asia in the 11th century and al-Marrākushī in Cairo in the 13th, both highly competent but neither particularly original. al-Bīrūnī relied heavily on his teacher al-Sijzī, who was familiar with developments in Baghdad in the 9th and 10th centuries, and al-Marrākushī's virtue (not to be underestimated) is that he seems to have incorporated into his *summa* every treatise on instruments that he could find. The treatise by Ibn al-Sarrāj's mysterious contemporary Najm al-Dīn al-Miṣrī, on the other hand, bristles with ingenuity, sometimes to the point of overkill, and contains numerous sections where the author loses control of his subject.

There were schools of instrument-makers, often several generations of the same family, functioning in the following major centres:

- ❖ Baghdad in the 9th and 10th centuries. We have the names of the most important of these and, happily, a few of their instruments (see now **XIIIb-c**).
- ❖ Various centres in al-Andalus in the 11th century (we have a dozen instruments), and especially Cordova and Toledo in that same century for universal astrolabes and plates (for these we have texts but no instruments). Isolated examples of Andalusī astrolabes survive from the next four centuries.
- ❖ Baghdad again in the 12th century: Hibatallāh and his followers.
- ❖ Isfahan from the 11th to 13th century. We have several instruments, especially those of Ḥāmid ibn Maḥmūd al-Iṣfahānī and his son Muḥammad, and Muḥammad ibn Abī Bakr al-Ibarī.
- ❖ Marrakesh and Seville in the early 13th century. See the numerous instruments of Abū Bakr ibn Yūsuf and al-Khamāʾirī, respectively, and their many imitators in later centuries.
- ❖ Damascus in the 13th century, whence the spectacular instruments of ʿAbd al-Raḥmān ibn Sinān al-Baʿlabakkī (**XIVc**) and ʿAbd al-Karīm al-Miṣrī.
- ❖ Northern Iran and Central Asia in the 14th and 15th centuries. We have several instruments by the al-Kirmānī family, of which the most important are those of Muḥammad ibn Jaʿfar al-Kirmānī known as Jalāl (see now **XIVd**).

- Granada in the 14th century, represented by the Ibn Bāṣo father-and-son team; a treatise by the father and several instruments by the son survive.
- Aleppo in the early 14th century. The context of Ibn al-Sarrāj and his remarkable instruments (see now **XIVb-5**) is unclear.
- Damascus in the 14th century. We have several unusual and sophisticated instruments, notably by Ibn al-Shāṭir and also al-Mizzī (see now **XIVb**), and numerous treatises.
- Delhi in the 14th century. Alas no instruments seem to survive, but we do have descriptions of several instruments made for Sultan Fīrūz Shāh Tughluq.
- Isfahan, and also Meshed, from the 17th to the 19th century: several prolific astrolabists, all competent but none in any way innovative, including Muḥammad Muqīm Yazdī, Muḥammad Zamān Mashhadī, Muḥammad Mahdī, Muḥammad Khalīl, ʿAbd al-ʿAlī, Muḥammad Ṭāhir, Muḥammad Amīn and ʿAbd al-Aʾimma.
- Lahore from the 16th to the 18th century. Apparently this activity started with Maqṣūd al-Hirawī; thereafter it continued mainly at the hands of one family stemming from Allāh-dād (or Ilāh-dād), generally more adventurous than their contemporaries in Isfahan.
- Istanbul from the 16th to the 19th century: numerous quadrants available, surprisingly few astrolabes.
- Marrakesh and Meknes from the 17th (?) to the 19th century, especially al-Baṭṭūṭī around 1700. Numerous instruments, mainly astrolabes, survive.

In the first two-thirds of the 20th century fake instruments were made in Iran. In the last third the scene moved to the Maghrib, and, more especially, India. See the next Chapter.

Besides the cross-references in the text, the following references may be useful. On instrumentation in Mamluk Egypt and Syria see most recently Charette, *Mamluk Instrumentation*, *passim*. On 14th-century Delhi see the important new study Sarma, "Sulṭān, Sūri and the Astrolabe". On the 17th-century Iranian schools see A. Turner in *Rockford TM Catalogue*, I:1, pp. 23-26; Savage-Smith, *Islamicate Globes*, pp. 32-60; and King, *Mecca-Centred World-Maps*, pp. 262-269. On the Lahore school see Sarma, "Lahore Astrolabists". On instrumentation in the Maghrib see King, "Astronomy in the Maghrib", pp. 40-42 and 47-52 (list of surviving Maghribi instruments). On the transmission of instrument-related ideas from one end of the Islamic world to the other see now Puig, "Andalusī Instrumentation in the Islamic East".

CHAPTER 11

CONCLUDING REMARKS

> "So ist unser Modell [*sic*: read Astrolab] (hergestellt in Iran (Eṣfahān?) im Jahre 1118/1706) ein interessantes Beispiel für die Periode der Dekadenz im Gebrauch des Astrolabiums im arabisch-islamischen Kuturraum, als man nicht mehr in der Lage war, es als astronomisches Beobachtungsinstrument zu gebrauchen." Fuat Sezgin & Eckhard Neubauer, *Wissenschaft und Technik im Islam* (2003), II, p. 110, describing what they did not realize was a wretched modern fake.

Numerous late copies of al-Marrākushī's *summa* on instrumentation survive, as well as countless late compilations of no great originality. Yet even in the mid 17th century the leading astronomer in Istanbul, known as Munajjimak (d. 1667), compiled another *summa* on instrumentation in the tradition of al-Marrākushī (only fragments of this have survived). Muslim interest in instrumentation continued into the 19th century and even into the 20th. Particularly astrolabes and quadrants were still being made, and there were still people who knew how to use them. Witness the detailed mathematical investigation of astrolabes, quadrants, and sundials published in Arabic and Turkish by Aḥmad Mukhtār Bāshā in Cairo as late as 1875. Similar interests were exhibited by Fatih Gökmen, the founder of Kandilli Observatory, who died in 1955: he compiled a booklet on the theory and practice of operations with the sine quadrant. But all this was too late for any wide-scale practical application in the traditional context.

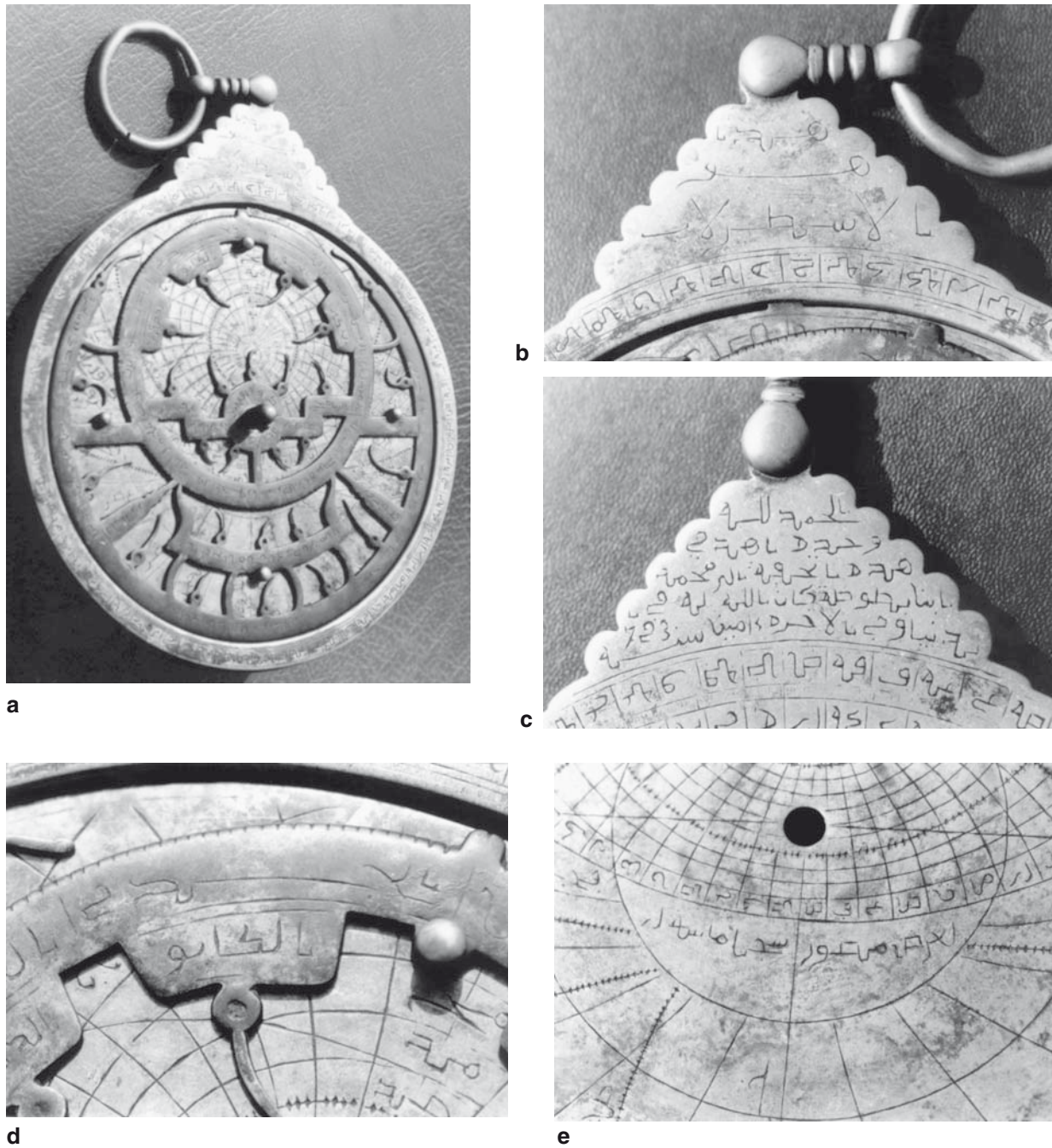
The study of Islamic instruments is but a small chapter in the history of Muslim interest in astronomy for over a millennium. The splendid miniature of the Observatory in Istanbul in the late 16th century (see **Fig. 1.1**) brings these instruments back to life again, and helps to save us from the antiquarian attitudes so prevalent amongst those who deal only with instruments. We need to be liberated from the notion that Islamic instrumentation is of consequence only as a prelude to European developments in this field. Various Islamic instruments and related mathematical procedures were influential in medieval Europe; indeed, instrumentation in medieval and Renaissance Europe can often barely be understood without reference to the Islamic tradition. For both the conception and design of Islamic instruments was highly influential in Europe, although this is often not immediately apparent. This is, of course, not to say that before, say, 1500, we do not find real innovations in medieval Europe: witness, for example, the some of the writings of Richard of Wallingford. In recent years, it has become increasingly obvious that moist of the major technical innovations in Renaissance instruments have their counterparts in earlier Islamic instrumentation. After all, before the introduction of the telescope, the interest in astronomy was similar in both milieus. There is as yet little published literature on this topic, which will surely attract some interest.

In general, it is fortunate for the history of Islamic instrumentation that the majority of important individual instruments are now preserved in major museums in the West, most of

which have administrations that further research. The oldest surviving Islamic astrolabe (8th century?) was housed, at least until recently, in the Archaeological Museum in Baghdad (**XIIIb**): inevitably, it is currently inaccessible. On the other hand, one instrument, namely the *Zīj al-ṣafā'iḥ* constructed by Hibatallāh (**5.3**), was lost for 50 years simply because it ended up in the West. Instruments such as sundials that have not come to enjoy the relative security of museums have suffered much abuse. Most surviving mosque sundials, which represent but a small fraction of those that once existed, are no longer functional because they have been divested of their gnomons. I have seen a gnomon on a sundial in Istanbul twisted to support a wire for a telephone and a sundial in Damascus covered by a modern drainpipe. On the other hand, the man responsible for regulating the prayer-times in the main mosque in Fez in the 1970s (captured in Nasr, *Islamic Science*, pl. 79 on p. 121) apparently still used a sundial when he could perfectly well have read the prayer-times from a daily newspaper or wall-calendar or have used the watch he was wearing to find the appropriate time to announce the call to prayer.

Islamic instrumentation came to a rather unhappy end in the late 20th century. Until the Islamic revolution astrolabes were fabricated in Iran for tourists, and now the major source of fakes appears to be India. Some of these are featured as genuine instruments—"India, *ca*. 1800"—in a recent catalogue of a large private collection in London. In the past ten years some very large instruments made recently in India have appeared at auction houses in London and Paris; some of these bear inscriptions which could fool any art-historian and even any Arabist for a while. An astrolabe made for the famous 14th-century traveller Ibn Baṭṭūṭa to take on his world voyage was on sale in Fez in the 1980s for US$ 75,000 (**Fig. 11.1**). Most of the Islamic astrolabes which pass through—that is, in and usually straight back out of—the major auction houses in London are fakes. And the majority of them are immediately identifiable as trash (**Fig. 11.2-3**).

On the same subject, it is an open question what kind of service has been done to our field by Fuat Sezgin in Frankfurt, with his monumental collection of models and reconstructions of Islamic instruments. This is not to say that this collection, and the richly-illustrated catalogues describing it, will not boggle the minds of most people who see them. And this is not to say that it may prove useful even for specialists to see reconstructions of instruments hitherto known only from texts. The sad thing is that the real instruments themselves attract so little interest, both from the museums that own them and from armchair historians who have never seen a historical instrument in their lives, let alone published one.

On the brighter side, perhaps, electronic watches and devices are now available for jetset Muslims that beep at the prayer-times and deliver recorded prayer-calls, and some even purr when properly aligned in the qibla. But these are a far cry from the call of the muezzin and also from the beautiful astronomical instruments of the past. There is much work still to be done on the latter, and there are surely important instruments unknown to us that are gathering dust in private collections, particularly those in Iran and India. But the instruments are many, and the workers very, very few.

Figs. 11.1a-e: At first sight this is a respectable medieval Maghribi astrolabe (a). But the inscriptions on the front of the throne (b) confirm "this is the astrolabe", and already we smell a rat. Those on the back (c) indicate that it was presented to the Ibn Baṭṭūṭa just in time for him to take it on his world voyage. The maker was not even able to write the star-name *al-ṭā'ir* (d) or the place names *Miṣr* (for Cairo) and *Sijilmāsa* (e) properly. Whoever bought this astrolabe from a very clever vendor in Fez tried to hawk it at Christie's and then at Sotheby's in the 1990s. Christie's sent me photos and I demolished it for them, but months later I just happened to be at Sotheby's on the very day when it was brought in for an estimate. The owner had left Christie's somewhat *maẓlūm* and he must have left Sotheby's *maẓlūm khāliṣ*. [Photos by the author.]

Figs. 11.2a-b: Most fakes are immediately recognizable as such. On this piece there are no star-names on the rete, but there are no star-pointers either (a). On the back is a ridiculous male figure identified as Saturn, and some nonsensical inscriptions mentioning Ptolemy and a certain star (b). On the mater are illustrations of the 12 zodiacal signs. [Photos courtesy of Christie's, London.]

Fig. 11.3: Again the rete on this astrolabe is a piece of junk. But the mater and plates are from a genuine astrolabe by the well-known and prolific astrolabist Ḥājjī ʿAlī (Isfahan, *ca*. 1700). For this reason I am always grateful for a chance to look through "junk" at Christie's or Sotheby's. [Photos courtesy of Christie's, London.]

On Munajjimak see *Cairo ENL Survey*, no. H23, and İhsanoğlu *et al*., eds., *Ottoman Astronomical Literature*, II, pp. 304-305 (no. 163). On Mukhtār Bāshā see *ibid*., II, pp. 701-706 (no. 543). On Fatih Gökmen see *ibid*., pp. 720-725 (no. 555). On the influence of Islamic instrumentation in the European Middle Ages and the reappearance of Islamic instrument types in the Renaissance see King, "Astronomical Instrumentation between East and West", pp. 144-145, 154, 156, 161, and 168-169, and some works still in preparation. Some remarks are in my "Review of G. Turner, *Elizabethan Astrolabes*", esp. pp. 149-150.

On fake Islamic instruments, see Brieux, "Authenticité des astrolabes"; Gingerich & King & Saliba, "The ʿAbd al-Aʾimma Astrolabe Forgeries"; *London Khalili Collection Catalogue*, pp. 195-196 and 199 (to be used with caution), and my review "Cataloguing Islamic Astronomical Instruments", esp. cols. 251 and 257-258. On fake European instruments, mainly "Renaissance" ones made in the 19th and 20th centuries, see Price, "Fake Antique Scientific Instruments". The same Delhi workshop that produced the fake Islamic astrolabes featured in *London Khalili Collection Catalogue*, pp. 237-238, nos. 135-136 (on which see my review, col. 257), is now also producing quite respectable-looking European instruments, confirming my hypothesis of the collaboration of a well-informed European or American—see now **XIVf-7**.

On the Frankfurt collection of replicas and models in the Institut für Geschichte der Arabisch-Islamischen Naturwissenschaften in Frankfurt, see now the five splendidly-produced volumes of Sezgin & Neubauer, *Wissenschaft und Technik im Islam* (2003). Vol. 1 purports to be an introduction to the history of science in Islam. However, it is based mainly on early writings on the subject and ignores most of the research that has been conducted since *ca*. 1950 except that by the principal author, some of which is highly controversial. The work would have been a real *Bahnbrecher* a century ago. In Vols. 2-3 on astronomical instruments, the innocent reader must take care to try to distinguish between copies of actual instruments, sometimes with dubiously rendered (or deliberately simplified) inscriptions, and models based on speculation from descriptions in textual sources and occasionally on sheer fantasy. I do not wish to imply any impropriety here, but it seems highly inappropriate that a reconstruction of al-Ṣūfī's celestial globe becomes in the title "*Der* Himmelsglobus von ʿAbdarrahḥmān al-Ṣūfī" (my italics). The bibliography on some of the individual astronomical instruments represented is not to be taken seriously, for authors now dead who mentioned the pieces in passing are cited with enthusiasm, but living authors who actually published the pieces in question in detailed studies are deliberately ignored. Likewise, the particularly Islamic aspects of Islamic science are also deliberately ignored, almost as if they were an embarrassment. A "real" astrolabe dated 1118 H [= 1706] from the collection of the Institute is included; it is a modern fake, and it is sad that the authors of this book could not even recognize it as such. The most useful parts of vol. 2 are perhaps the reconstructions of observational instruments and equatoria. I leave it to others to judge the rest for themselves.

Part XI

An approximate formula for timekeeping from 750 to 1900

To Yas Maeyama

DEDICATION, ACKNOWLEDGEMENTS AND NOTES ON THIS VERSION

By definition a Japanese engineer trained in Japan who then works in Brazil and who then becomes professor of the history of science in Germany is unique. But Yas Maeyama is unique amongst Japanese ex-engineers and German professors because of his warmth, kindness and consideration for others, and no less for his passion for his chosen subject, the history of astronomy from Antiquity to early modern times. It has been my pleasure to work alongside him since 1985, to marvel at his tenacity and insights *vis-à-vis* complicated problems in the history of mathematical astronomy, be it Chinese, Babylonian, Greek or early modern European. Some 25 of his scholarly productions are now reprinted in a weighty tome entitled *Astronomy in Orient and Occident — Selected papers on its cultural and scientific history*, Hildesheim, Zurich, New York: Georg Olms, 2003. The studies treat specific quantitative problems of positional astronomy from China to Babylon and from Greece to Central Europe during a period of over 3,000 years. It was also my privilege to have occasionally enjoyed a Pils or two with him after work, and to savour the delights of his cooking. I wish him many more years of creative activity.

The first version of this study was written with considerable assistance and encouragement from Dorothea Girke. It is the fruit of a seminar on Islamic astronomical instruments at the Institute of the History of Science in Frankfurt during the Summer Semester of 1988. The subject was the unique Dublin (Chester Beatty) manuscript of an anonymous 14th-century treatise in which the author described and illustrated over 100 instrument-types known to him from his predecessors or invented by himself. Dorothea Girke was the sole participant in this seminar, but we plodded away and read parts of this and other related texts together and discussed them *ad nauseam*. There is the famous story of the German professor who had no students at all attend his lectures but stood there and read his lectures anyway. This "German professor" was delighted that one interested doctoral student was there to share the excitement of working on previously-unstudied materials. Whether I would have written the *history of a formula* had it not been for the seminar is an open question. But in any case it seemed like a good idea at the time and we certainly had a lot of fun. Dr. Richard Lorch of Munich made various corrections to the first draft of the study and useful comments thereon, but he bears no responsibility for any remaining defects.

In the first version of this study, the anonymous treatise in the Chester Beatty manuscript with all of its tables for latitude 36° (serving Aleppo) was attributed by me without question, and not totally without good reason (who else was there in Aleppo at the time?), to Ibn al-Sarrāj. It has since been shown by François Charette that this treatise is in fact by Najm al-Dīn al-Miṣrī, who worked in Cairo, but for reasons best known to himself, included in his work tables serving the latitude of the 4th climate, which does not, in fact, serve Aleppo very well

at all. (The explanation may be that our author was influenced by the diagrams for 36° in the treatise on astrolabe construction by al-Bīrūnī.) Not only does Ibn al-Sarrāj go up in my estimation with Charette's discoveries, but also Najm al-Dīn al-Miṣrī. The interested reader should consult Charette's *Mathematical Instrumentation in Fourteenth-Century Egypt and Syria*, which goes far beyond the present study in its analysis of Najm al-Dīn's remarkable and ideosyncratic work. I am grateful to François Charette for checking this new version for consistency and accuracy, not only to ensure that all of the "superfluous Ibn al-Sarrājs" have been suppressed. I have also removed all of the translations laboriously made by Dorothea Girke and myself of the relevant sections of the treatises of al-Marrākushī and Najm al-Dīn al-Miṣrī, not least to encourage the reader to consult the translations of Sédillot-*père* and Charette. Also, the reader should keep in mind that at the time when I wrote this study I was primarily interested in applications of the universal formula and the theory underlying the various astronomical instruments, rather than the instruments themselves. Furthermore, the text was written before I really became involved with instruments on a full-time basis.

I have not modified the basic text in the light of my new study of the universal horary quadrant in **XIIa**, written some 14 years after the first version of this one, but, in an attempt to minimize the inevitable duplications, I have added a few cross-references and moved some of the illustrations from **XI** to **XIIa**. *Möge die Übung gelingen*!

TABLE OF CONTENTS

SUMMARY

This study deals with an approximate formula for finding the time of day from an observed solar altitude for any latitude which was widely used for over a millennium, by astronomers both in the Near East and Europe, by some wittingly and by others in total innocence. The extent to which it was used is now apparent: numerous medieval tables for timekeeping are based on this formula and most horary quadrants likewise. These represent respectively numerical and graphical representations of the formula.

I illustrate the utility of the formula and the associated tables and instruments and draw attention to their limitations. The formula does serve as a reasonable approximation for most practical purposes in latitudes corresponding to the region where it was introduced (India or Iran?) and first extensively used (Iraq), but it is less reliable in the higher latitudes of Europe.

From the 9th century onwards, Muslim astronomers compiled tables based on our formula and purporting to be universal: these displayed either the time of day in seasonal hours as a function of the instantaneous solar altitude or the solar altitude as a function of the time of day. Some of these tables made their way to Europe and Byzantium. It can also be shown that certain Islamic timekeeping tables for specific latitudes are based on the approximate formula.

Various Muslim astronomers tried their hand at devising instruments marked with graphical representations of our formula. One of these bears the name of the 8th-century astronomer al-Fazārī. Two astronomers of the Mamluk Cairo, al-Marrākushī (*ca*. 1280) and Najm al-Dīn al-Miṣrī (*ca*. 1325), exploited such graphical representations for all that they were worth.

We shall see that the most popular variety of universal horary quadrant is but a simple and elegant development of the earliest form of trigonometric quadrant, devised specifically for reckoning time with the formula (this was hypothesized already by Richard Lorch in 1981). Both of these instruments date from the early 9th century, and the earliest texts on them were compiled in Baghdad. The universal horary quadrant needs only a thread or an alidade attached at its centre to achieve its purpose; it does not, contrary to some claims in the modern literature, need a radial solar scale or a movable cursor around its rim to make it work for a particular latitude. However, the Arabic texts inform us that the universal horary quadrants were sometimes fitted with movable cursors, a combination also known from 11th-century Europe as *quadrans vetus*: the Near Eastern origin of this instrument is thus now firmly established.

The introduction of the so-called *quadrans novus* in Europe in the 13th century is often hailed in the modern literature as a great step forward, but the main function of the instrument—timekeeping—is nevertheless approximate, and, for latitudes as high as those in Europe, unsatisfactory. The most original feature of the *quadrans novus*, the representation of the ecliptic and local horizon on a quadrant, had been achieved in Egypt at least two centuries prior to its introduction in Europe. The combination of universal hour-lines and a stereographic representation of the ecliptic and horizons for particular latitudes on the Profatius quadrant is

an unhappy one. Notwithstanding this defect the *quadrans novus* was popular for several centuries in Europe; it was, however, not known in the Islamic world.

Muslim astronomers favoured the more satisfactory, mathematically accurate astrolabic quadrant for a specific latitude, introduced in Egypt in the 11th or 12th century. They devised several varieties, of which, however, only one—the standard astrolabic quadrant with a trigonometric grid on the back—was widely manufactured. This instrument, unknown in medieval Europe, remained popular with them until the 19th century. Horary quadrants for specific latitudes are known to have been made from *ca*. 825 onwards in the Near East. These became very popular in later European astronomy. Some of these instruments, which concern us here, were adapted from the universal horary quadrant by the provision of a solar scale devised to restrict the markings to a specific latitude.

A survey of Islamic horary quadrants for a specific latitude has been prepared in a parallel study by Mercè Viladrich. More recently, François Charette has contributed a new study of such instruments within the context of Islamic instrumentation generally. In the European tradition until *ca*. 1700 even horary quadrants for a fixed latitude also bore universal markings in addition to the main markings. Islamic astrolabic quadrants for a fixed latitude up to as late as *ca*. 1900 also bore such markings. In both cases this is a tribute to the versatility of the graphic representation of our approximate formula, which in its original form had, by the early modern period, been long forgotten by all concerned.

Our formula, its virtues and its limitations, are nowhere adequately described in the modern literature on the history of astronomy or on astronomical instrumentation. Yet to write the history of this approximate formula is to take it out of its context as a companion to the accurate formula. I have shown in **I** and **II** what Muslim astronomers could do with the accurate formula, including here and there tables based on this approximate formula. Also, in **VIa-b** I have shown how the passion of Muslim astronomers for universal solutions based on the accurate formula manifested itself. Furthermore, I have shown in **III** and **IV** what Muslim legal scholars did with an even simpler, arithmetical formula for timekeeping. So now we consider the trigonometric approximate formula in isolation. It is first necessary to realize that the formula is approximate because it is universal and independent of latitude, also that it works singularly well in the latitudes in which it was first proposed. Part of the historical importance of the formula is that it underlies the universal horary quadrant, a highly ingenious instrument that has been misunderstood and even abused in the modern literature. We consider the history of this quadrant here below, and then again in more detail in **XIIa**.

CHAPTER 1

INTRODUCTION

"... the only true waste of time is that of counting hours." Gargantua, quoted by Sigrid and Klaus Maurice, "Counting the Hours" (1980), p. 156.

"Il est sûr que la méthode est inexacte. (al-Marrākushī) paraît n'en sentir la raison, et l'espèce d'incertitude qu'il laisse entrevoir ne ferait pas beaucoup d'honneur à ses connaissances théoriques." Jean-Jacques Sédillot (*père*), *Traité* (1834-35), I, p. 250.

"Les arcs des heures égales tracés (sur un diagramme des heures inégales), s'écartent peu des arcs des heures inégales, et quand on superpose les deux, la figure devient confuse." Henri Michel, *Traité de l'astrolabe* (1947), p. 84.

"All (Islamic) approximate methods and instruments are related to a formula for timekeeping of Indian origin. ... . We shall encounter in Najm al-Dīn's treatise numerous instruments, notably sundials, based on the application of this formula. ... . Yet the main objective of Mamluk authors in *mīqāt* was to develop methods and to design instruments that are fully universal, without the cost of approximation. ... . The introductions of Mamluk works on instrumentation reflect the obsession of their authors for universal solutions. Universality was a major virtue." François Charette, *Mamluk Instrumentation* (2003), p. 22.

"Truth is much too complicated to allow anything but approximations." The mathematician John von Neumann (b. Budapest, 1903, d. Washington, D.C., 1957), quoted in *The Mathematical Intelligencer* 10:2 (1988), p. 47.

1.1 Astronomical timekeeping in the medieval Near East and Europe

The mathematical formula for reckoning the time of day from an observed altitude of the sun or any non-circumpolar star is not trivial, involving several trigonometric functions as well as various arithmetical operations. The formula was first derived in ancient India, and it became known to Muslim scholars in the 8th or 9th centuries as a result of their contact with these Indian sources. Serious astronomers were not daunted by it, and indeed most of the impressive activity of the Muslim scientists in astronomical timekeeping from the 9th to the 16th century, both in the development of instruments as analogue or computational devices and the preparation of enormous tables for timekeeping for specific latitudes, involved *accurate* trigonometrical procedures (**I-II**).

Alongside the astrolabe the astronomers used quadrants and sundials of different kinds. Yet it was known that calculation would yield more precise results than operations with analogue or computational instruments. Thus corpuses of tables were compiled for the major centres of this activity (in particular Cairo, Jerusalem, Damascus, Taiz, Tunis, and Istanbul), these containing anything between 5,000 and 100,000 entries. The tables displayed the time since sunrise, and/or the hour-angle as a function of instantaneous solar altitude, sometimes with solar longitude as the second argument, sometimes with the solar meridian altitude; the duration of morning and evening twilight; and the times of the day-light prayers (which in Islam are defined in terms of shadow-lengths).

Most of this activity was unknown in medieval Europe, and those Arabic astronomical works

that were translated did not include tables for timekeeping. The early development of timekeeping in al-Andalus and Sicily is obscure indeed, there being simply no sources of consequence preserved. The first European tables for timekeeping are usually simple ones showing nothing more than the solar altitude at the hours and specifically intended for the construction of portable sundials. By the 14th century a more sophisticated corpus such as that compiled in Oxford also included tables for twilight (**I-10.1-2**).

1.2 Two approximate formulae for timekeeping

Now the earliest Muslim astronomers also adopted two approximate Indian formulae for deriving the time of day more simply, one arithmetical and the other trigonometric. The arithmetical formula, which relates the time of day in seasonal hours to the increase of the shadow over its midday minimum, does not concern us here, though see **12** and the detailed study in **IV**. The trigonometric formula works reasonably well for practical purposes and was used, sometimes explicitly but more often implicitly, by various groups throughout the medieval period.

As we shall see, the formula underlies various tables for timekeeping preserved in the Arabic sources, and—I suspect but cannot yet prove—also in the Latin sources. It also inspired various instruments for timekeeping invented in the 9th century and used throughout the Middle Ages, again in both the Near East and the Latin West. Already in 1819 Jean-Baptiste Delambre pointed out that the most popular variety of horary quadrant functions only approximately,[1] and in 1925 Joseph Drecker established that with this instrument the time was given according to our approximate formula.[2] José Millás Vallicrosa appears to have been the first modern scholar to associate the specific formula attested in medieval texts with the horary quadrant.[3] In an insightful study published in 1980 Richard Lorch hypothesized that the horary quadrant had been derived from the simple trigonometric quadrant,[4] a theory that I can happily support.

On the other hand, most modern descriptions of such instruments, the simple horary quadrant common on the backs of astrolabes or the *quadrantes vetus* and *novus*, usually ignore the fact that these rely on an approximate procedure. I shall also see how two Muslim astronomers of note, namely al-Marrākushī and Najm al-Dīn al-Miṣrī, exploited this formula for all that it was worth. Their other writings attest to their competence in astronomical instrumentation generally and also the compilation of accurate tables based on complicated trigonometrical procedures, as well as—at least in the case of Najm al-Dīn al-Miṣrī (al-Marrākushī was more eclectic)—in the invention of ingenious new instruments. Their involvement with the approximate formula is to be seen as yet another episode in the history of Muslim interest in solutions to problems of spherical astronomy for all latitudes (**VIa-b**).

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[1] Delambre, *HAMA*, pp. 243-247.
[2] Drecker, *Theorie der Sonnenuhren*, pp. 86-87.
[3] Millás Vallicrosa, "Cuadrante con cursor", pp. 91-92.
[4] See Lorch, "Universal Horary Quadrant". (The argumentation is somewhat obscured because the hour-angle in degrees is considered rather than the time since sunrise in seasonal hours.) The versatility of the earliest form of the trigonometric quadrant is well illustrated in *idem*, "Sine Quadrant".

1.3 The sources used for the present study

Our main sources are:

1.3.1 The treatise on astronomical timekeeping by the celebrated early-11th-century scientist of Central Asia, al-Bīrūnī, extant in MS Bankipore 2468,36, copied in 632 H [= 1234/35], and published in an uncritical edition in Hyderabad in 1948, and translated with commentary by Ted Kennedy in 1976.[5] al-Bīrūnī has preserved for us fragments of various very early Islamic astronomical writings, including two in which our formula is attested.

1.3.2 Two collections of short treatises with tables, probably to be associated with the well-known early-9th-century Baghdad astronomer al-Khwārizmī,[6] preserved in MS Istanbul Ayasofya 4380 (especially fols. 185v-204r, copied in Damascus in 626 H [= 1229]) and MS Berlin Landberg 56 = Ahlwardt 5793 (fols. 77v-97r, copied *ca*. 1500 probably in Egypt or Syria);[7] and an anonymous Abbasid treatise on the horary quadrant preserved in MS Cairo DM 969,4 (fols. 8v-9v, copied *ca*. 1800, probably in Meshed).[8] On this last see now **XIIa**. In addition, an anonymous Andalusī treatise, possibly from the 12th century, on twelve different kinds of horary quadrants, preserved in MS Cairo ṬM 155,3 (fols. 19r-21v, copied *ca*. 1700, probably in Egypt).[9]

1.3.3 A series of astronomical handbooks with tables, called *zīj*es in Arabic and preserved in various manuscripts, which happen to contain material relevant to this study.[10] The most useful of these turns out to be a Syrian recension of the *Zīj* of Ibn Isḥāq, who worked in Tunis in the early 13th century. This precious source is preserved in the unique copy MS Hyderabad Andra Pradesh State Library 298 (200 fols., copied *ca*. 1400).[11]

1.3.4 The *summa* on astronomical instruments compiled by al-Marrākushī in Cairo in the late 13th century. This work was the object of two monumental studies by the Sédillots *père et fils* in

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5 On al-Bīrūnī (**II:2.2**) see the article by E. S. Kennedy in *DSB*. For translation of, and commentary on, his treatise *On Shadows* (Sezgin, *GAS*, V, p. 380) see Kennedy, *al-Bīrūnī's* Shadows, I and II.

6 On al-Khwārizmī (**II:3.1**) see the article by Gerald Toomer in *DSB*. On the Berlin manuscript see *Berlin Catalogue*, p. 227. The Istanbul manuscript is uncatalogued, and only parts of its contents have been listed in the reference works of Max Krause and Fuat Sezgin. The relevant parts of both manuscripts were studied briefly, and in a very preliminary fashion, in King, "al-Khwārizmī", pp. 7-11. A new study of all of the materials on instrumentation associated with al-Khwārizmī is in Charette & Schmidl, "al-Khwārizmī on Instruments".

7 *Berlin Catalogue*, p. 227.

8 *Cairo ENL Survey*, no. B105.

9 *Cairo ENL Survey*, no. F6. The dating follows from the fact that al-Marrākushī (see n. 1:12) used a treatise of this kind for his survey of horary quadrants for a specific latitude. The connection with al-Andalus follows from the other treatises in the manuscript. See now Viladrich, "Horary Quadrants".

10 On Islamic *zīj*es see Kennedy, "*Zīj* Survey". In 1956 Kennedy was able to list 125 such works; now some 200 are known to have been compiled between 750 and 1750: see the new overview in King & Samsó, "Islamic Astronomical Handbooks and Tables", with a shorter version in the article "Zīdj̲" in *EI*2. I have usually not inserted references to this new overview because it will shortly be rendered redundant by the new *zīj* survey that has been prepared by Dr. Benno van Dalen in Frankfurt.

11 On Ibn Isḥāq and his *Zīj* (**II-13.1**) see now Mestres, "Hyderabad MS of the *Zīj* of Ibn Isḥāq", and *idem*, Zīj *of Ibn Isḥāq*.

the 19th century.[12] It is available in several manuscript copies, of which I have used MS Istanbul Topkapı A.III 3343 (*ca*. 375 fols., copied in 1346). Only Carl Schoy has worked on the text since the time of the Sédillots, but in his various writings on Islamic gnomonics[13] he did not treat of the universal sundials that I describe in this paper.

1.3.5 The treatise on the construction of astronomical instruments by the Cairene astronomer Najm al-Dīn al-Miṣrī (*ca*. 1325).[14] This is extant in MS Dublin CB 102,2 (fols. 28v-99v, copied *ca*. 1350) and an incomplete copy (38 fols., also *ca*. 1350) recently auctioned at Christie's of London.[15] This remarkable work contains descriptions not only of all instruments invented by him but also of all instruments known to him; it thus supplements the *magnum opus* of al-Marrākushī. (It is not known whether Najm al-Dīn al-Miṣrī intended, or actually achieved, the compilation of a companion volume on the use of these instruments.) Although his predecessor al-Marrākushī had exploited our formula for almost all that it was worth, Najm al-Dīn al-Miṣrī was not at a loss to devise yet more instruments based on it. His manipulations with our formula will probably also surprise a reader or two.

1.3.6 In October, 1988, as the first version of this study was in its final stages, I quite by chance came across some photographs of a "Treatise on geometry" attributed to the Aleppo astronomer Ibn al-Sarrāj (*ca*. 1325)[16] preserved in MS Princeton Yahuda 4657 (4983), consisting of *ca*. 15 fols., copied *ca*. 1500 (?).[17] This turns out to be a fragment of a substantial treatise on instrumentation, some of which were invented by Ibn al-Sarrāj. The investigation of the Princeton manuscript is a task for the future.[18] He describes six basic varieties of trigonometric quadrant described by the author. His prowess in the field of universal solutions is already well established now that his remarkable quintuply-universal astrolabe has been studied.[19]

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[12] On al-Marrākushī (**I-4.2.4** and **II-2.7** and **6.7**) and his role in Mamluk astronomy see the article in *EI*$_2$ and King, "Astronomy of the Mamluks", pp. 539-540. The first part of his treatise dealing with spherical astronomy and sundials was translated in Sédillot-*père*, *Traité*; a survey of the second part dealing with other instruments is in *Sédillot-fils*, *Mémoire*. A facsimile "edition" of the Topkapı manuscript in two volumes, albeit with new pagination (and the original foliation deliberately removed), was published by the Institut für Geschichte der Arabisch-Islamischen Wissenschaften in Frankfurt in 1984.

[13] See Schoy, *Gnomonik der Araber*, *passim*, and other articles reprinted in *idem*, *Beiträge*.

[14] On Najm al-Dīn (Suter, *MAA*, no. 460; *Cairo ENL Survey*, no. C16; and King, "Astronomy of the Mamluks", p. 540) see the new study Charette, *Mamluk Instrumentation*. The Dublin manuscript contains a treatise on the use of his universal table for timekeeping (**I-2.6.1**) as a universal auxiliary table for solving all problems of spherical astronomy (**I-9.3***).

[15] The Dublin manucript was described amongst Persian manuscripts in *Dublin CB Persian Catalogue*, pp. 2-3. I first encountered this manuscript in the summer of 1982, and in all writings up to 1999 have referred to it as a work by Ibn al-Sarrāj—see King, *Mecca-Centred World-Maps*, p. xxix, for an apology. The other copy was first described in *Christie's London 11.04.2000 Catalogue (Islamic Art and Manuscripts)*, pp. 14-17 (lot 22), written by François Charette and myself. On these two manuscripts, see now Charette, *Mamluk Instrumentation*, pp. 28-43.

[16] On Ibn al-Sarrāj (*Suter, MAA,* no. 508 (confused)) see *Cairo ENL Survey*, no. C26, and King, "Astronomy of the Mamluks", pp. 544-546, also **X-5.2** and the references cited in n. 19.

[17] On the manuscript see *Princeton Catalogue* (not available).

[18] An extensive commentary on this work by Ibn al-Majdī (Cairo, *ca*. 1450—see Suter, *MAA*, no. 432, and *Cairo ENL Survey*, no. C62) is in MS Damascus Ẓāhiriyya 4133 (142 fols., copied *ca*. 1500), of which I had acquired a microfilm in the 1970s—see now Charette, "Der geflügelte Quadrant", esp. p. 27.

[19] See already King, "The Astronomical Instruments of Ibn al-Sarrāj", first published in *idem*, *Studies*, B-IX, amd now **XIVb-5.1**. A detailed study is in Charette & King, *The Universal Astrolabe of Ibn al-Sarrāj* (forthcoming).

1.3.7 Various relevant Hebrew, Byzantine and European sources, including an English manuscript of the *Toledan* and *Alphonsine Tables*, miscellaneous texts on astrolabes and horary quadrants, and a 14th-century Spanish treatise on astrology. I make no claim to have exhausted such sources, having relied mainly on what is published; however, it seems reasonable to suppose that most of this material—with the exception of the unhappy *quadrans novus*—owes its inspiration to the Islamic tradition.

And, last but not least:

1.3.8 Various Near Eastern and European instruments, known to us from the long-outdated survey of astrolabes by Robert T. Gunther and the same author's earlier study of astronomical instruments in his *Early Science in Oxford*, as well as various catalogues of individual collections.[20] The catalogues of auctions at Christie's and Sotheby's also contain useful descriptions. The forthcoming inventory of Islamic instruments by Francis Maddison and the late Alain Brieux promises to revive some interest in this aspect of the history of Islamic astronomy;[21] and my long-term project to catalogue all medieval Islamic and European instruments continues slowly.[22] What we know about such instruments will remain very much a matter of chance until the surviving pieces are catalogued. I make no claim here to have dealt systematically with the European material; nevertheless, where I can point to parallel developments in European instrumentation, I have done so.

I have edited and translated all known early treatises on the quadrant, but this material is not yet published. Horary quadrants for a specific latitude are now described in a new study by Mercè Viladrich[23] and those described by Najm al-Dīn al-Miṣrī are treated in greater detail and within their historical context by François Charette.[24]

1.4 The notation used in the analysis

No great mastery of spherical astronomy, or even of trigonometry, is necessary to understand the material presented in this study. Seasonal hours—used in Antiquity and throughout the Middle Ages in popular practice—are one-twelfth divisions of the length of daylight or night; they thus vary throughout the year and only at the equinoxes are the day-hours the same length as the night-hours. Clearly the time of day depends upon the altitude of the sun, but also upon the season and the local terrestrial latitude; in fact, the time of day (in equatorial degrees since sunrise or before midday) on a particular day in a specific locality can be—and generally was

[20] See Gunther, *Early Science in Oxford*, II, and *idem*, *Astrolabes*. The major catalogues are listed in **X-1**.

[21] See Brieux & Maddison, *Répertoire* (forthcoming). Previously the fundamental reference work was Mayer, *Islamic Astrolabists* (Islamic astrolabes, quadrants, and sundials, very reliable but long outdated).

[22] See King, "Medieval Instrument Catalogue". This project began after the completion of the first version of the present study.

[23] Viladrich, "Horary Quadrants". More information on the instruments of this kind presented by Najm al-Dīn al-Miṣrī is provided by Franćois Charette (see next note), who is anyway more reliable on the mathematical aspects of the quadrants.

[24] Charette, *Mamluk Instrumentation*, pp. 113-139.

in medieval astronomy—expressed trigonometrically in terms of the observed solar altitude and the solar meridian altitude and half length of daylight on the day in question. But already in the medieval period astronomers also used an equivalent formula (similar to the modern one) in which the time is expressed in terms of the instantaneous altitude, the celestial declination, and the local latitude. Most of the instruments I shall describe also serve the determination of the time of the *ʿaṣr* prayer in the mid-afternoon (it is understood that the *ẓuhr* prayer begins just after midday)—on the definitions of the time of the daylight prayers in Islam see **IV**.

I use the following notation freely:

a	azimuth (measured from the prime vertical)
a	as a subscript, relates to the *ʿaṣr* (mid-afternoon) prayer
d	excess of half the length of daylight over 90°
D	half the length of daylight (= 90° + d)
h	solar altitude (negative for depression below horizon)
h	as a superscript, equinoctial hours
H	solar meridian altitude
i	number of seasonal hours (1, 2, ... , 6); as a subscript, relates to the i^{th} seasonal hour
n	length of gnomon (usually 12 units); as a subscript, relates to length of gnomon
r	duration of morning twilight; as a subscript, relates to morning twilight
R	base for medieval trigonometric functions (= 150 or 60 for Sine, 12 for Cotangent or Tangent); radius for quadrants
s	duration of evening twilight; as a subscript, relates to evening twilight
sdh	seasonal day hours, also as a superscript
snh	seasonal night hours, also as a superscript
t	hour-angle
T	time since sunrise before midday, time before sunset after midday
z	horizontal shadow
z′	vertical shadow
Z	horizontal shadow at midday
Z′	vertical shadow at midday
δ	declination
Δz	increase of horizontal shadow over midday minimum (= z - Z)
λ	solar longitude
λ'	ecliptic longitude measured from nearer equinox
λ^*	longitude of opposite point on ecliptic ($\lambda^* = \lambda + 180°$)
ϕ	local latitude
$\bar{\theta}$	complement of θ

I also use the standard modern notation for medieval trigonometric functions to bases other than unity. Thus:

$$\mathrm{Sin}_R\ \theta = R \sin \theta \quad \text{and} \quad \mathrm{Cot}_n\ \theta = n \cot \theta.$$

Typical of very early Islamic works is the use of R = 150, as in the Indian tradition; later R = 60 predominated. For shadow functions the use of n = 12 or n = 7 was the most common.

All entries in the tables are expressed sexagesimally to base 60. Numbers in Arabic, Hebrew, and (Byzantine) Greek sources are written in the appropriate alphanumerical notation, and in the European tables in the Roman or the Hindu-Arabic systems.

CHAPTER 2

THE APPROXIMATE TRIGONOMETRIC FORMULA FOR TIMEKEEPING

2.0 Introductory remarks

The simple trigonometric formula relating T to h and H, which satisfies the boundary conditions that T = 0 when h = 0 and T = 6 when h = H, and which also works reasonably well for all seasons of the year and all sensible terrestrial latitudes,[1] is the following:

$$T = \{ {}^{1}/_{15} \text{ arc Sin } [\text{ R Sin h / Sin H }] \}^{sdh}$$

In fact the formula is exact for any latitude when the sun is at the equinoxes, for then $1^{sdh} = 15°$. In various *zīj*es it is therefore often given as a special case of the accurate solution.[2]

Those who used the formula in the medieval period assumed—implicitly or explicitly—that it was valid for all solar declinations at all sensible terrestrial latitudes. Both al-Marrākushī and Najm al-Dīn al-Miṣrī (**3.6** and **3.7**) were happy to advocate its use for latitudes between 0° and 48°, that is, within the seven climates of classical Antiquity.[3] Other Muslim astronomers thought that beyond these limits there was nobody interested in astronomy anyway.[4]

2.1 Attestations of the formula

The formula apparently occurs for the first time in the *Hārūnī Zīj*, an unidentified work probably from the 8th century, known to us only from a passage in the treatise *On Shadows* by the celebrated 11th-century scientist al-Bīrūnī (**1.3.1** and **Text 1**).[5] There the formula is expressed

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1 A yet simpler formula, namely:

$$T = {}^{1}/_{15} \text{ arc Sin } \{ R \cdot h / H \}^{sdh},$$

does not appear to have been used by ancient or medieval astronomers. It has the drawback that it is not even valid at the equinoxes and also that for H = 90° the values of h_i are not precisely 15°, 30°, *etc*. See also n. 2:14. (This is not to say that approximate methods involving inverse trigonometric ratios of quotients of arcs were not used in early Islamic astronomy; for example, one of the earliest techniques for finding the local direction of Mecca was based on a simple latitude-longitude grid, from which the qibla could be found as the angle in a right-angled triangle with opposite side the longitude difference from Mecca and adjacent side the latitude difference.) al-Marrākushī mentions the rule:

$$T = \{ h / 15 \}^{sdh}$$

for the (very) special case H = 90°—see **2.2**.

2 See, for example, King, *Ibn Yūnus*, III-15.3a.

3 On the climates in the Islamic tradition see the references cited in n. **I**-1:11, and also **XVI-2-3**.

4 For example, Abū Naṣr (*fl.* Central Asia, *ca.* 1000): see Jensen, "Abū Naṣr's *Table of Minutes*", p. 5; and King, "al-Khalīlī's Universal Auxiliary Tables", p. 108, n. 19.

5 For this passage see Kennedy, *al-Bīrūnī's* Shadows, I, pp. 196 and 198, and II, pp. 123-124. Sezgin (*GAS*, V, p. 225) makes of *al-Zīj al-Hārūnī* a *zīj* compiled during the time of the Caliph Hārūn al-Rashīd. This is reasonable, but it is surprising that we have no other references to such a work.

in Cosecants, these being the hypotenuses of the right-angled triangles formed by the gnomon and the shadows; also, the time is expressed in *kardaja*s (k), where $1^k = 15°$.[6] The formula given in words can be rendered thus:

$$T = \text{arc Sin}_{150} \{ 150 \text{ Cosec}_{12} H / \text{Cosec}_{12} h \}^k.$$

al-Bīrūnī also attributes an equivalent formula:

$$T = {}^1/_{15} \text{ arc Sin}_{150} \{ [1800 / \text{Cosec}_{12} h] \cdot [150 / \text{Sin}_{150} H] \}^h$$

to Yaʿqūb ibn Ṭāriq, the mid-8th-century astronomer who played a major role in the introduction of Indian astronomy into the lands of Islam.[7] The fact that our rule is mentioned in such sources, and the fact that time is measured in *kardaja*s indicates, as E. S. Kennedy has already noted, that it is derived from Indian or Sasanian techniques.[8] The formula is indeed attested in Indian sources, although I deliberately refrain from trying to list them.[9] Note that Yaʿqūb ibn Ṭāriq stated that the time given by the formula was in *equinoctial* hours rather than seasonal hours (see also below).

The formula occurs next in the writings of al-Khwārizmī (on whom see **1.3.1**). In the only extant version of his *zīj*—a Latin translation of an Andalusī redaction—there is no material of consequence on the main problems of timekeeping. However, from the commentary on his *zīj* by the 10th-century Andalusī astronomer Ibn al-Muthannā—available in two Hebrew versions—it is clear that both the approximate and the accurate methods were advocated by al-Khwārizmī.[10] Also he was the inventor of the trigonometric quadrant, developed for timekeeping with this very formula (**8.1**). The formula applied to the specific problem of determining the duration of twilight occurs in an anonymous recension of the *zīj* of the celebrated mid-9th-century astronomer Ḥabash al-Ḥāsib (**5.0**).

I find it somewhat surprising that al-Bīrūnī in his survey of Islamic procedures for finding the time from solar or stellar altitudes only mentions our formula in connection with the two very early sources mentioned above. Where it underlies the procedures for timekeeping advocated in various treatises on instruments from the 9th century onwards or numerous tables also from the 9th century onwards, it is invariably not explicitly stated. (See **4.1** on an exception.) Without having conducted a systematic search for the formula in the Islamic literature on mathematical astronomy, I am confident that our formula is seldom mentioned: most astronomers simply presented the accurate formula.

The formula occurs in the Latin version of the *Canons* of the 11th-century Toledan scholar Ibn al-Zarqālluh (Spanish form: Azarquiel).[11] Furthermore, in his treatise on his universal plate,

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[6] On the concept of *kardaja* in the early Islamic sources see Goldstein, *Ibn al-Muthannā on al-Khwārizmī*, pp. 196-197, 200; Kennedy & Pingree & Haddad, *al-Hāshimī on Astronomical Tables*, p. 214. See also n. 9:13.

[7] On Yaʿqūb see Pingree, "Yaʿqūb ibn Ṭāriq"; the article by the same author in *DSB*; and Sezgin, *GAS*, V, pp. 217-218, VI, pp. 124-127, and VII, pp. 101-102. On his use of the formula see especially Pingree, "Yaʿqūb ibn Ṭāriq", p. 121.

[8] Kennedy, *al-Bīrūnī's* Shadows, II, p. 123.

[9] For a start, see the references cited in n. 7 above, and also Pingree, "Indian Astronomy", pp. 539-540 and 541.

[10] See Goldstein, *Ibn al-Muthannā on al-Khwārizmī*, pp. 82-83 and 207-209. (Ibn al-Muthannā was apparently not aware that the two formulae were not equivalent.)

[11] On Ibn al-Zarqālluh see the article by Juan Vernet in *DSB* and the literature there cited, especially Millás, *Azarquiel*. On the attestation of the formula see Curtze, "Urkunden zur Geschichte der Trigonometrie", pp. 338-340, and Millás, *Azarquiel*, pp. 46-48.

and in the Hebrew, Middle Castillian, and Latin translations thereof, it is clearly stated that the determination of T(h,H) with this instrument provides approximate solutions but the underlying formula is not stated. The single trigonometric grid of the variety known in Arabic as *shakkāziyya* and in the Latin West as *saphea* was widely used in both the Near East and Europe thereafter (**8.3**).

Probably from the works of Ibn al-Zarqālluh the formula was taken over into the *Zīj* of Ibn Isḥāq (**1.3.2**), the most substantial work on astronomy compiled in the Maghrib. Note that Ibn Isḥāq, in applying the formula to determine the duration of twilight (**5.4-5**), seems to have confused equinoctial and seasonal hours, as Yaʿqūb ibn Ṭāriq had done about five centuries previously.

It is clear that the formula was known and used in medieval Europe beyond the Pyrenees—not simply because of its occurence in the Azarquiel tradition—but I know of no direct attestation of it in the European sources apart from the table based on it in the Toledan and Alfonsine tradition (**3.11**).

In the Byzantine MS Paris BNF gr. 2425, copied in the 15th century, there are miscellaneous chapters and tables, much obviously lifted from Islamic sources (notably al-Khwārizmī and Ḥabash); both the approximate and accurate formulae for timekeeping are described and there is also a reference to a table based on the former.[12]

2.2 al-Marrākushī and Najm al-Dīn al-Miṣrī on the formula

The most extensive use of our formula is made by al-Marrākushī and Najm al-Dīn. The former devoted Book I, Ch. 39, of his *magnum opus* to it, appending various tables based on it, and then later describing four related instruments (**3.5-6**). This material is available to us in the translation of Jean-Jacques Sédillot (*père*). al-Marrākushī criticized those who thought that the formula was universally valid and he was well aware that the errors resulting from it increased with latitude. But in his opinion it was a very useful formula, which could be used for most practical purposes for all latitudes in the inhabited world (by this he meant up to latitude 48°, the limit of the seventh climate[13]). Sédillot-*père* misunderstood the introduction to this chapter and mistranslated it; to add insult to injury, he also made some disparaging remarks about al-Marrākushī's grasp of his subject (see the quote at the beginning of this study). al-Marrākushī knew full well that the formula was approximate!

It is of interest that al-Marrākushī began his discussion by presenting a special case when H = 90°, namely:

$$T = {}^{1}/_{6}\, h\,.$$[14]

This underlies the markings on a special kind of sundial described in **XIIa-C**.

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[12] Neugebauer, "Byzantine Treatise", esp. pp. 11-12 and 40-41, and Jones, *Byzantine Manual*, pp. 44-45 and 126-127 (text and translation) and 154-155 and 174 (commentary).

[13] Sédillot-*père* (*Traité*, I, p. 250) incorrectly stated that al-Marrākushī meant latitudes up to 66°.

[14] See also n. 2:1.

Najm al-Dīn did not specifically state the formula in its general form. Rather—and probably to avoid being criticized for mimicking al-Marrākushī—he advocates in two places (Chs. 57 and 61) finding h_i by means of the simplified rule:

$$\text{Sin } h = c_i \text{ Sin } H ,$$

where the coefficients c_i are given as simple fractions, thus:

$$c_1 = {}^1/_4 , c_2 = {}^1/_2 , c_3 = {}^1/_2 + {}^1/_5 , c_4 = {}^2/_3 + {}^1/_5 , c_5 = 1 - {}^1/_{30} .$$

The sexagesimal equivalents:

0;15 0;30 0;42 0;52 0;58

compare quite favourably with the accurately computed values of Sin (15i)°/R to two digits, namely:

0;15,32 0;30,0 0;42,26 0;51,58 0;57,57.

The fact that Najm al-Dīn used these coefficients to calculate h_i explains certain curiosities in his tables—for example, the value h_1 = 14;30° rather than 15;0° for H = 90° (**3.6b** and **Fig. 3.6b**)—and in his construction of the markings on the horary quadrant—for example, the radius of the circle for the first hour being exactly twice the radius of the quadrant (**9.1**). Najm al-Dīn described some five different instruments based on the formula (**Ch. 7**).

2.3 On the accuracy of the formula

Tables 2.3a-b show the errors incurred by using the formula at the solstices in different latitudes—15° (Yemen), 30° (Cairo), 36° (Aleppo), and 48° (Europe)—at each 10° of altitude and at each seasonal hour, respectively. The errors, expressed in equatorial degrees (1° = 4 minutes of time) and derived according to the convention:

error = time by formula - accurate time ,

are of a different sign and larger in the summer than in the winter, and they increase from maxima of about -3/+2 minutes in the Yemen to almost -20/+6 minutes in Central Europe.[15]

Table 2.3
Errors in time in equatorial degrees incurred by using the formula

a: Errors at each 10° of altitude

		h	10°	20	30	40	50	60	70	80
ϕ	15°	SS	+0;21	+0;31	+0;32	+0;26	+0; 8			
		WS	–0;24	–0;37	–0;42	–0;41	–0;37	–0;29	-0;19	-0; 5
	30	SS	+0;46	+1; 1	+0;47					
		WS	–1; 1	–1;33	–1;44	–1;42	–1;31	–1;13	-0;49	-0;21
	36	SS	+0;59	+1; 9	+0; 6					
		WS	–1;25	–2; 7	–2;22	–2;17	–2; 0	–1;32	-0;56	
	48	SS	+1;26							
		WS	–2;55	–4; 8	–4;24	–4; 3	–3;14	–1;56		

[15] A thorough investigation of the accuracy of the formula is in Puig, ed., *al-Šakkāziyya*, pp. 68-72 (the maximum errors for different latitudes graphed on p. 71 do not seem to be large enough).

Table 2.3. Cont.

b: Errors when the formula yields the hours

	Hours		1	2	3	4	5
ϕ	15°	SS	–0;30	–0;41	–0;39	–0;29	–0;16
		WS	+0;23	+0;32	+0;31	+0;23	+0;13
	30°	SS	–1;17	–1;41	–1;35	–1;11	–0;38
		WS	+0;42	+0;58	+0;57	+0;44	+0;24
	36°	SS	–1;46	–2;17	–2; 8	–1;36	–0;51
		WS	+0;49	+1; 8	+1; 7	+0;52	+0;28
	48°	SS	–3;23	–4;14	–3;53	–2;53	–1;31
		WS	+0;59	+1;24	+1;23	+1; 5	+0;35

CHAPTER 3

MISCELLANEOUS UNIVERSAL TABLES FOR TIMEKEEPING BASED ON THE FORMULA

3.0 Introductory remarks

Most Islamic tables for timekeeping by the sun display the functions t and/or T in terms of arguments h and λ or h and H for a specific latitude (**I-2**). These either are, or purport to be, based on exact formulae. To make a table based on an accurate formula which would serve all latitudes was not beyond Najm al-Dīn al-Miṣrī, but it involved his computing some 440,000 entries (**I-2.6.1** and **I-9.3***). Tables displaying the functions T(h,H) and/or h(T,H) and/or the corresponding horizontal or vertical shadows z(T,H) or z′(T,H) for all latitudes based on the approximate formula are attested in several Islamic sources and at least one European manuscript of the *Toledan* and *Alphonsine Tables*, one Hebrew manuscript, and one Byzantine Greek manuscript (**I-10.2**).

The following is a list of these. The time T as a function of h and H may be tabulated in seasonal hours and minutes or equatorial degrees and minutes. Tables with arguments h and H are trapezoidal in shape since 0 < h < H; such tables are called *ṭaylasān* in medieval Arabic, the term referring to a shawl (**I-1.4**). In each of the tables of h values are given for each seasonal hour and each degree of H. All entries are to two sexagesimal digits unless otherwise stated.

3.1 A table of solar altitudes by al-Khwārizmī

In an anonymous extract on the trigonometric quadrant, probably by al-Khwārizmī, preserved in MS Berlin Ahlwardt 5793 (**1.3.1**), fol. 94v, there is a table of h(T,H) with entries to one digit with H starting at 25°—see **Fig. 3.1**.[1] See also **I-4.3.1** and **9.2** below.

3.2 A table by ʿAlī ibn Amājūr

The 10th-century Baghdad astronomer ʿAlī ibn Amājūr[2] compiled a work entitled *Zīj al-Ṭaylasān* in which he tabulated T(h,H) in equatorial degrees and minutes for latitude 33;25° (Baghdad) based on the exact formula (**I-2.3.1** and **II-3.2**) and T(H,h) in seasonal day hours and minutes for all latitudes with H starting at 1° (!) based on the approximate formula (**I-2.5.1**). His original work is lost, but the two tables are found in MS Paris BNF ar. 2486, copied in 1285, fols. 239r-

[1] See already King, "al-Khwārizmī", pp. 7, 10, 11, and Charette & Schmidl, "al-Khwārizmī on Instruments", p. 189.

[2] On Ibn Amājūr see Kennedy, "*Zīj* Survey", no. 8, *etc*.; Sezgin, *GAS*, VI, pp. 177-178.

Fig. 3.1: A table of h(T,H) by al-Khwārizmī computed with the approximate formula. [From MS Berlin Ahlwardt 5793, fol. 94v, courtesy of the Deutsche Staatsbibliothek (Preußischer Kulturbesitz).]

255r, of the *Zīj* of the 13th-century scholar Jamāl al-Dīn al-Baghdādī,[3] and MS Paris BNF supp. pers. 1488, copied in the 16th (?) century, fols. 201v-204v, of the Persian *Zīj-i Ashrafī* by the 14th-century astronomer Sanjar al-Kamālī of Shiraz.[4]

3.3 An anonymous table for Baghdad

The anonymous MS Paris BNF ar. 2514, copied in 1215, contains a set of tables for timekeeping including values of $T^{sdh}(H,h)$ for all latitudes (**I-2.5.2**) as well as of $T(H,h)^h$ for the latitude of Baghdad (also **I-2.5.2**, and further **4.3** below).

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[3] On al-Baghdādī see Kennedy, *op. cit.*, no. 3; and Sezgin, *op. cit.*, VI, p. 178.
[4] See Kennedy, *op. cit.*, no. 4, and Storey, *PL*, II:1, pp. 64-65, no. 98.

3.4 A table by Muḥyi ʻl-Dīn al-Maghribī

In MS Medina ʿĀrif Ḥikmat *mīqāt* 1, fols. 196r-196v, copied in 1292, of the *Zīj* for Maragha by the mid-13th-century astronomer Muḥyi ʻl-Dīn al-Maghribī, but in none of the other available manuscripts of his various *zīj*es, there is a table of h(T,H) (**I-4.3.1***).[5]

3.5 Some tables by al-Marrākushī

In al-Marrākushī's work (**II-6.7**) there are altogether five tables based on our formula.[6] They display the following functions to two sexagesimal digits (see **Fig. 3.5** for the first three):

(a) z′(T,H) for T = 1 to 6sdh and H = 5°, 10°, ... , 90°;
(b) z(T,Z) and z′(T,Z) for T = 1 to 6sdh and Z = 1, 2, ... , 36 (the maximum value of Z, namely, 36, occurs at the winter solstice at latitude 48°);
(c) z′(T,Z′) for T = 1 to 6sdh and Z′ = 1, 2, ... , 12;
(d) h(T,H) for T = 1 to 5sdh and H = 5°, 10°, ... , 90°, to be used in the construction of the universal conical sundial—see **Fig. 6.3**; and
(e) a function f(T,H) labelled *al-ẓill al-mustaʿmal* for T = 1 to 5sdh and H = 5°, 10°, ... , 90°, to be used in the construction of the vertical sundial called the *sāq al-jarāda* with fixed gnomon—see **Fig. 6.2**.

3.6 Some tables by Najm al-Dīn al-Miṣrī

The relevant tables presented by Najm al-Dīn,[7] specifically intended for constructing his universal sundials (**Ch. 7**), are of the following functions, with values to two sexagesimal digits:

(a) h(T,Z) for T = 1 to 5sdh and the ʿ*aṣr* and Z = 0, 2, 4,...., 36 (Ch. 61, fol. 77r, **Fig. 3.6a**), to be used for constructing sundials 1 and 2;
(b) h(T,H) for T = 1 to 5sdh and the beginning and *end* of the ʿ*aṣr*, and H = 10°, 20°, ... , 90° (Ch. 76, fol. 94r, **Fig. 3.6b**) to be used for sundial 5;
(c) z(T,H) for T = 1 to 5sdh and the ʿ*aṣr* and H = 10°, 20°, ... , 90° (Ch. 63, fol. 86v, **Fig. 7.3a**), to be used for sundial 3;
(d) z′(T,H) for T = 1 to 6sdh and H = 10°, 20°, ... , 90° (Ch. 64, fol. 87r, **Fig. 7.4a**), to be used for sundial 4.

The values generally differ from those in al-Marrākushī's tables because Najm al-Dīn used an additional approximation (**2.2**). Najm al-Dīn says the tables are valid for latitudes between 0° and 48°.

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[5] Kennedy, *op. cit.*, nos. 41 and 108, and *Cairo ENL Survey*, no. G21.
[6] Sédillot-*père*, *Traité*, I, pp. 253-257, 445, 448-449.
[7] The tables are edited in Charette, *Mamluk Instrumentation*, Arabic section, and can be accessed by the appropriate chapter number in Najm al-Dīn's text.
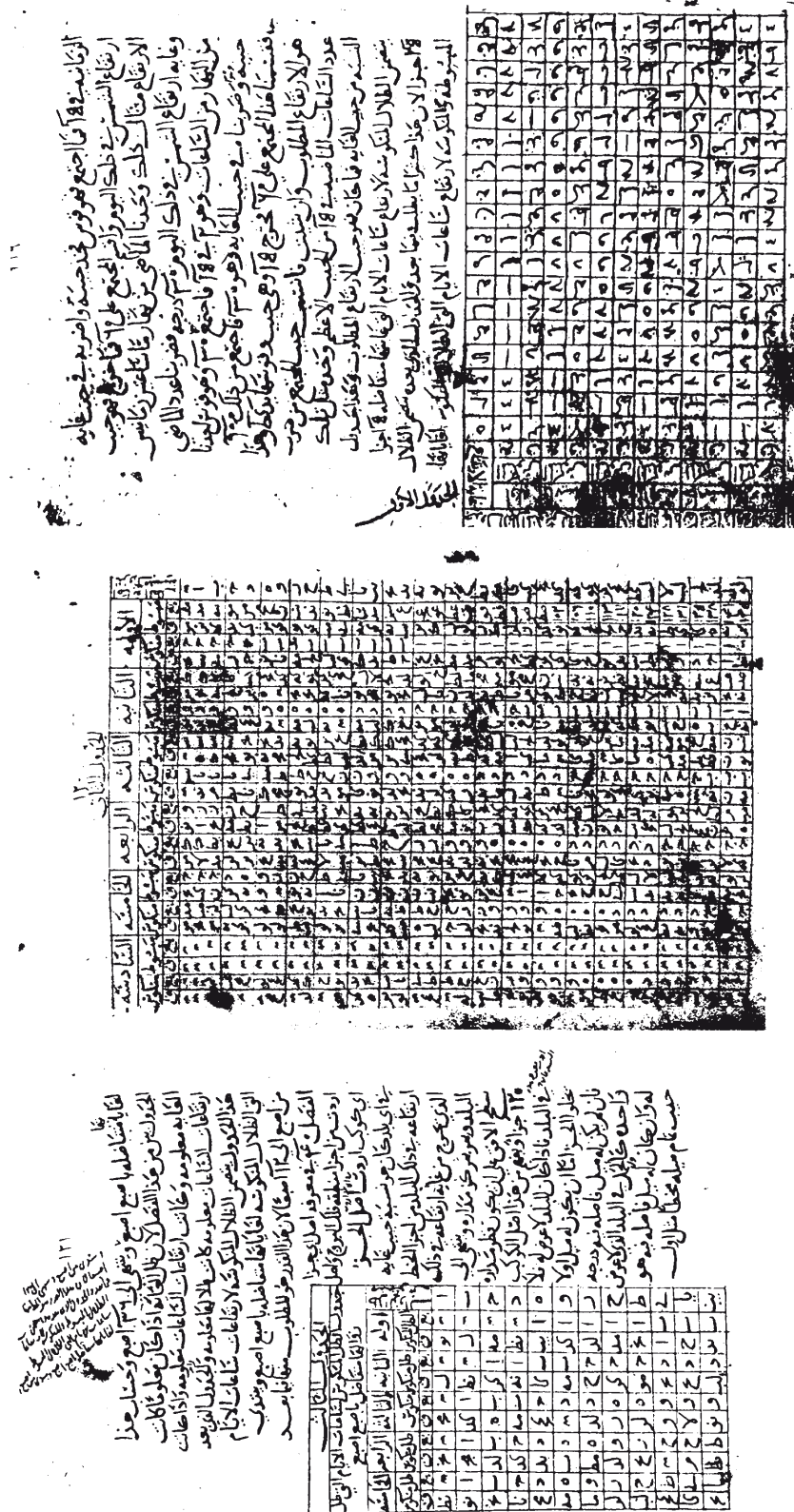
Fig. 3.5: Three of al-Marrākushī's tables of the shadows at the hours, displayed as functions of different arguments, such as the solar altitude at midday, and the horizontal or vertical shadows at midday. [From al-Marrākushī, *A-Z of Astronomical Timekeeping*, I, pp. 119-121.]

Fig. 3.6a: Najm al-Dīn's table of the shadow lengths at the hours as a function of the midday shadow. [From MS Dublin CB 102,2, fol. 77r, courtesy of the Chester Beatty Library.]
Fig. 3.6b: Najm al-Dīn's table of the solar altitude (and stellar altitude for stars with declination less than the obliquity) as a function of the meridian altitude. See **2.2** on the scheme behind this table. [From MS Dublin CB 102,2, fol. 94r, courtesy of the Chester Beatty Library.]

3.7 An anonymous Yemeni table

The anonymous Yemeni *zīj* preserved in MS Paris BNF ar. 2523 and compiled *ca*. 1375[8] contains (fols. 97v-100v and 86r) tables of T^{sdh}(h,H) for arguments H starting at 46° and h(T,H) for H starting at 51° (**I-2.5.3** and **4.3.3**).

3.8 Another Yemeni table by al-Daylamī

The Yemeni *zīj* compiled by Muḥammad al-Daylamī *ca*. 1520 and extant in a unique manuscript (copied in 1680) housed in a private collection in Zabid[9] contains two tables of h(T,H) with H starting at 51° and 40°, respectively (**I-4.3.4**). The entries differ from those in **3.7**.

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[8] King, *Astronomy in Yemen*, pp. 36-37.
[9] *Ibid*., pp. 41-42.

3.9 An anonymous table

In MS Baghdad Awqāf 2966/6294, fol. 136r, of a hodge-podge of tables from the 14th and 15th centuries, including some by the 14th-century Damascus astronomer Ibn al-Shāṭir,[10] there is a table of h(T,H) with H starting at 1° (**I-4.3.5**). In MS Leiden Or. 65, fol. 110r, of a recension of the *Zīj* of Ibn al-Shāṭir there is a similar, if not identical, table. I have not come across such a table in any manuscripts of the original *Zīj*. In MS Princeton Yahuda 147c of a *zīj* for Tunis compiled by the 17th-century astronomer Ḥusayn Quṣʿa,[11] there is a page ruled for a table with identical title and format to the one in the Baghdad manuscript, but no entries have been copied (**I-4.3.6**).

3.10 A table in the Arabic Zacuto corpus

In MS Milan Ambrosiana C82 of the Maghribī version of the perpetual almanac of the late-15th-century Jewish astronomer Abraham Zacuto of Salamanca[12] there are various additional tables, one of which (fol. 144v) displays values of h(T,H) for all latitudes to one digit for H starting at 1°. See further **I-4.3.7**.

3.11 A table in the Latin sources

In MS Oxford Digby 68 (or should this be 168?), copied in England in the 14th century, there is a mixture of tables from the Toledan and Alphonsine corpuses including a table of h(T,H) for all latitudes (fols. 65r-72r) with entries carefully computed to two digits for each 0;15sdh of T and each 0;30° of H from 10° to 90°.[13] See futher **I-10.1**.

3.12 A table in the Hebrew sources

A table of T(H,h) with entries in Hebrew alphanumerical notation is in MS Munich heb. 343, fols. 41v-46v.[14] Values are given for each 5 days of the year and each degree of h. See further **I-10.1**.

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[10] On Ibn al-Shāṭir see Kennedy, "*Zīj* Survey", p. 125 (no. 11); King & Samsó, "Islamic Astronomical Hanbooks and Tables", pp. 48-49 and 75-76; and the article in *DSB*.

[11] King, "Astronomy in the Maghrib", p. 35; Samsó, "Maghribi *Zīj*es", p. 9; and King & Samsó, *op. cit.*, 63.

[12] On Zacuto see the article by Juan Vernet in *DSB*, and now Chabás & Golstein, *Zacut*, where such tables for timekeeping are not mentioned as being part of the main Zacuto corpus. On the manuscript and this particular table see now Samsó, "Zacut in the Islamic East", pp. 70-72 and 84.

[13] See Toomer, "Toledan Tables", pp. 12 and 155

[14] Information kindly provided by Professor Bernard Goldstein, Pittsburgh, and working copies of the tables by Dr. Richard Lorch, Munich.

3.13 A table in the Byzantine sources

In MS Vatican graecus 1056, copied in the 14th century, fols. 41r-41v, Alexander Jones has found a fragment of a Byzantine table of $T^{sdh}(h,H)$ (κανον των ωρων). Precisely such a table is mentioned in the text of MS Paris BNF gr. 2425, copied in the early 14th century, but no table of this kind is contained in that manuscript now.[15] See further **I-10.1**.

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[15] Jones, *Byzantine Manual*, pp. 18, 44-45, 126-127, and 174.

CHAPTER 4

SOME TABLES FOR SPECIFIC LATITUDES BASED ON THE FORMULA

4.0 Introductory remarks

In some of the tables described in the previous section the range of argument H is limited to correspond to a specific latitude or region. But there is another way to adapt the results yielded by our formula for a specific latitude. The formula gives time in seasonal hours, and values can be converted to equinoctial hours or degrees by applying a factor appropriate to that particular latitude and meridian altitude. Such applications of our formula are discussed in this section.

4.1 A table for constructing an horary quadrant for Baghdad

A short anonymous Abbasid treatise on the construction of an horary quadrant for latitude 33° (Baghdad) is contained in MS Istanbul Ayasofya 4830 (**1.3**), fols. 196v-197r—see **Fig. 4.1a**.[1] The solar longitude can be inserted on an ecliptic scale on either of the axes, and the solar altitude is measured on a scale on the circumference. On fol. 197r there is a table of $h_i(\lambda)$ for each pair of opposite signs, with values to one digit (**I-4.2.2**), its function being to facilitate marking the hour-curves on the quadrant (**Text 3**). The text states that the approximate formula was used to compile the table. This treatise is the earliest known description of an horary quadrant for a fixed latitude; the construction of such instruments was not widespread in the later period of Islamic astronomy but it continued until *ca*. 1700 in Europe—see **11.2** and **11.4** and also **X-6.3**.

In passing I mention a table of a similar function appended to al-Khwārizmī's treatise on the astrolabe and the trigonometric quadrant in MS Berlin Ahlwardt 5793 (**1.3**), fol. 97v—see

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Fig. 4.1a: An anonymous Abbasid table of solar altitude for marking an horary quadrant for the latitude of Baghdad. See **Figs. XIIIc-8.1b** and **9i** for such quadrants on the backs of early astrolabes. [From MS Istanbul Ayasofya 4830, fol. 197r, courtesy of the Süleymaniye Library.]
Fig. 4.1b: A curious table of 9th-century provenance, whose function has yet to be determined. [From MS Berlin Ahlwardt 5793, fol. 97v, courtesy of the Deutsche Staatsbibliothek (Preußischer Kulturbesitz).]
Figs. 4.1c-d: An illustration of a conical sundial in an anonymous Abbasid treatise, together with a table of vertical shadows for engraving the astronomical markings. [From MS Istanbul Ayasofya 4830, fols. 192r-v, courtesy of the Süleymaniye Library.]

[1] See already King, "al-Khwārizmī", pp. 30-31, and now Charette & Schmidl, "al-Khwārizmī on Instruments", pp. 157-158, and 182-183.

4.1a

4.1b

4.1c

4.1d

Fig. 4.1b.[2] The tabulated values are close to those of $h_i(\lambda)$ for Baghdad, but I have been unable to derive the optimal parameters ϕ and ε (even from the entries for the 6th hour), and I suspect that another function has been tabulated, but which?

A treatise on a conical sundial for Baghdad is contained in MS Istanbul Ayasofya 4830 (see above), fols. 192v-193r—see **Figs. 4.1c-d**.[3] A table of the necessary shadows $z_i(\lambda)$ is presented, with values for each pair of signs, scaled so that the maximum value is 30. I have not investigated the underlying parameters and structure. This is the earliest known treatise on such a sundial, dating probably from the 9th century—see further **6.3**.

Each of these three sources merits further investigation.

4.2 An anonymous timekeeping table for Iran

One of the numerous Islamic tables of T(h,H) which survive is one for an unspecified locality in Iran preserved in MS Leiden Or. 199,3, fols. 21v-27v, copied *ca*. 1300 (**I-2.3.4**): see **Fig. 4.2**. This table is distinguished by the fact that it was the first such table to be investigated in modern times, namely, in a study by Bernard Goldstein published in 1963.[4] The argument H runs in steps of 1° from 30° to 78°, which led Goldstein to the reasonable conclusion that the underlying latitude was 36° and that the author may have assumed 24° for the obliquity. Besides, the entry for h = H = 54° is 90°, which is what one would expect at the equinoxes. This notwithstanding, there are numerous problems with the table: many entries are hopelessly corrupt, and there are places where the copyist lost control of the format so that certain entries are misplaced. In general Goldstein found the entries carelessly computed; certainly errors as large as 2° would have been frowned upon by more competent contemporaries.

The table is admittedly in bad shape, but there is more that can be said about it. Firstly there is a page of the manuscript that was not available to Goldstein, immediately preceding the Persian introduction (fol. 21r). The introduction describes how to use the table of T(h,H) to find the horoscopus at any time of day, a simple procedure provided one has a table of oblique ascensions at hand.[5] Precisely such a table is found on fol. 21r, and the heading states that it serves latitude 37;40°. In fact it is very accurately computed for parameters:

$$\phi = 37;0° \quad \text{and} \quad \varepsilon = 23;35°.$$

Several significant localities in Greater Iran are associated with the latitude 37;40° in the medieval sources, but the most likely one intended, which is attested in far more geographical tables over the centuries, is Marw. On the other hand, 37;0° is not attested for Marw.[6] However,

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[2] *Ibid*., pp. 27 and 29.

[3] Not listed in Krause, "Stambuler Handschriften" or Sezgin, *GAS*, (like various other anonymous works in this precious manuscript)—see n. 1:6.

[4] See Goldstein, "Medieval Table for Reckoning Time from Solar Altitude".

[5] On oblique ascensions see the article "Maṭāliʿ" in EI_2, and also **I-7**.

[6] Kennedy & Kennedy, *Islamic Geographical Coordinates*, pp. 219-220, 692-693 and 695.

This table is not the same as the one in the *Sanjarī Zīj* of ʿAbd al-Raḥmān al-Khāzinī, compiled in Marw *ca*. 1125. al-Khāzinī used 37;40° for Marw. On this work see Kennedy, "*Zīj* Survey", p. 129 (no. 27) and pp. 159-161; and King & Samsó, "Islamic Astronomical Handbooks and Tables", p. 45.

Fig. 4.2: An extract from the anonymous Iranian table for timekeeping based on a mixture of exact and approximate procedures. [From MS Leiden UB Or. 199,3, fols. 21v-22r, courtesy of the Universiteitsbibliotheek.]

the entries in the main table for timekeeping are not based on this latitude and were not computed by the same person; rather, they were computed for $\phi = 36°$ using the approximate formula. One computes $T^{sdh}(h,H)$ universally and then applies an appropriate factor for the local situation. This involves first finding the maximum length of half-daylight, that is, $D(H) = T(h,H)$ for $h = H$, using the standard formula:

$$D(H) = 90° + \text{arc Sin}_R \{ \text{Tan } \delta \text{ Tan } \phi / R \}$$

with the declination δ derived from:

$$\delta = H - \bar{\phi}.$$

Then the entries for a specific H are generated using:

$$T(h) = D / 90° \bullet \text{arc Sin}_R \{ R \text{ Sin } h / \text{Sin } H \} .$$

For a latitude of about 36° one would then anticipate errors up to 2°, and Goldstein noted maximum errors of this order.

4.3 A dubious timekeeping table for Baghdad

The table of $T(H,h)^h$ in MS Paris BNF ar. 2514 (**3.3** and **I-2.5.2**) gives values for $33° \leq H \leq 80°$, which limits the underlying latitude to *ca*. 33;30° (probably for Baghdad). However, the entries are so corrupt that during a preliminary investigation I found it impossible to confirm that the entries were simply derived from the corresponding values of $T^{sdh}(H,h)$ by multiplying them by a factor derived from the appropriate declination.

4.4 Miscellaneous European tables

As I shall show below (**11.3-4**), various Muslim and European instrument-makers marked their universal horary quadrants with scales for the solar longitude (if only the equinoxes and solstices). This attempt to tie the hour-curves to a specific latitude is equivalent to adapting the tables of $T^{sdh}(H,h)$ to a specific latitude with upper and lower limits on H, as in the unfortunate table described in **4.2**. I confess to having suspected that the simple solar altitude and shadow tables for specific latitudes found in various early European sources were based on our formula.

However, the table of solar altitude at the hours for latitude 48° in the treatise on the astrolabe attributed to Hermannus Contractus (1013-1054),[7] which displays $h_i(\lambda)$ ($\Delta\lambda = 30°$) to one digit, was not computed according to the standard approximate formula. In fact, the author states that he derived the entries using an astrolabe and he must have done this carefully with a well-made instrument for they do indeed correspond quite well to computation with the exact formula. The published version of a table of $z'_i(\lambda) = \mathrm{Tan}_{12}\, h_i(\lambda)$ ($\Delta\lambda = 30°$) for latitude 47;46° (Vienna) compiled by John of Gmunden (*fl*. *ca*. 1430) for marking the hour-curves on a cylindrical sundial[8] is full of errors but not based on our formula. Likewise the more substantial tables for Paris associated with Jean Fusoris (*fl*. *ca*. 1400)[9] and for Oxford by Nicholas of Lynn (compiled 1386)[10] are based on accurate procedures.

On the other hand, the tables of $h_i(H)$ for the equatorial hours and each degree of H computed for Baeza (latitude 38°) by pseudo-Enrique de Villena (**I-10.1**)[11] display an error pattern which could be taken as implying that they were based on the approximate formula; however, the table may have been compiled using an instrument such as an astrolabe: even the values at the equinoxes contain errors of as much as 2°.

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[7] On Hermannus see the article by Claudia Kren in *DSB*. For the table see Gunther, *Early Science in Oxford*, II, p. 419 (but it is not contained in the treatise translated in Drecker, "Hermannus Contractus über das Astrolab").
[8] On John of Gmunden see the article by Kurt Vogel in *DSB*. The table is published in Kren, "Traveller's Dial", esp. p. 431.
[9] For the tables see Poulle, *Fusoris*, pp. 184-185 and 186.
[10] See Eisner, *Kalendarium of Nicholas of Lynn*, on Nicholas and his tables.
[11] See Cátedra & Samsó, *Astrología de Enrique de Villena*, pp. 171-176, and the commentary on pp. 56-57.

Although I have not been able to find any European altitude tables based on our formula, I should not be surprised if some turn up eventually.[12] A survey of all European tables for timekeeping would be a useful contribution: see **I-10.1-2** for a start.

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[12] Zinner, *Astronomische Instrumente*, pp. 159 and 50-51, also lists tables for Oxford, London, Rome, Venice, Nuremberg, Augsburg and Regensburg, which I have not investigated. See North, *Richard of Wallingford*, I, p. 18, on a table for Oxford by John Maudith (14th century), and *idem*, *Chaucer's Universe*, p. 114, on various other tables of this kind.

CHAPTER 5

THREE TABLES FOR TWILIGHT FOR SPECIFIC LATITUDES AND ONE UNIVERSAL TWILIGHT TABLE BASED ON THE FORMULA

5.0 The underlying principle

Most Islamic tables for the duration of morning and evening twilight, $r(\lambda)$ and $s(\lambda)$ are based on the accurate formula. Underlying the tables are the solar depression at daybreak and nightfall, h_r and h_s, and in most cases the tables of $r(\lambda)$ and $s(\lambda)$ are simply taken from larger corpuses of tables for timekeeping displaying the hour-angle or the time since sunrise, $t(h,\lambda)$ or $T(h,\lambda)$, these functions being tabulated for each degree of both arguments for a specific terrestrial latitude. The connection is simply:

$$r(\lambda) = T(-h_r,\lambda) = T(h_r,\lambda^*) \quad \text{where } \lambda^* = \lambda + 180°,$$

which follows from a simple consideration of the celestial sphere (see **II-4.10**). If one does not have the more extensive tables at hand, then the tables for twilight have to be computed independently.

The approximate formula:

$$s(\lambda) = \{ \ {}^{1}/_{15} \ \text{arc Sin} \ [\ R \ \text{Sin} \ h_s \ / \ \text{Sin} \ H(\lambda^*) \ ] \ \}^{\text{sdh}}$$

with parameter(s) h_s (= h_r) = 18° is attested in the anonymous recension of the *Zīj* of Ḥabash (*fl*. Baghdad, *ca*. 850) extant in MS Berlin Ahlwardt 5750, copied *ca*. 1300 (especially fol. 153v, see **Text 5**).[1] This procedure may not be original to Ḥabash. However, there is evidence that it was used in later practice.

5.1 A twilight table for Baghdad

In MS Paris BNF ar. 2486, fols. 120v-122r, copied in 1285, of the *Zīj* of al-Baghdādī (**3.2**), there is a set of prayer-tables for Baghdad in which one function tabulated is the number of seasonal hours and minutes from sunset to daybreak for each degree of solar longitude λ (**II-3.3**). This function, labelled simply *ṭulūʿ al-fajr*, "daybreak", is: $f(\lambda) = 12 - s(\lambda)$, where $s(\lambda)$ is defined as above with h_s = -17°. The underlying latitude is 33;25°, a standard value for Baghdad[2] also used in al-Baghdādī's tables for spherical astronomy. It is probable that al-Baghdādī lifted these tables from some earlier source.

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[1] See *Berlin Catalogue*, pp. 200-203; Kennedy, "*Zīj* Survey", pp. 126-127 (no. 15) and pp. 151-153; also Debarnot, "*Zīj* of Ḥabash", pp. 35-36 and 63-65.

[2] Kennedy & Kennedy, *Islamic Geographical Tables*, pp. 55-56.

5.2 A twilight table for the latitude of the fourth climate

In MS Paris BNF ar. 5968, copied *ca*. 1250, fols. 187v-188r, of the anonymous Ismā'īlī *Zīj* known as the *Dustūr al-munajjimīn*, apparently compiled in Northern Syria,[3] there are two similar tables for twilight for latitude 36;21°[4]—see **II-3.7** (illustrated). The tables display the duration of evening twilight and the time from sunset until daybreak in seasonal night hours and minutes, and values are based upon parameters $h_r = h_s = -16°$ although $h_r = -18°$ and $h_s = -17°$ are mentioned in the accompanying text. Again values are computed according to the approximate procedure.

5.3 A twilight table for Tunis

A page of MS Hyderabad 298 of the *Zīj* of Ibn Isḥāq (**1.3.3** and **2.1**) is ruled for a twilight table (no. 348) but no values have been copied. The argument was the solar longitude and the values were to have been given in (seasonal) hours and minutes; the table must therefore have been computed for a specific latitude. I conclude that Ibn Isḥāq prepared a table of r(λ) for Tunis based on our formula.

5.4 A universal twilight table

In Ch. 41 of the *Zīj* of Ibn Isḥāq there is a reference to a table is referred to which is alas no longer contained in the unique Hyderabad manuscript.[5] From the title and the argument headings we can infer that the argument was H*, the meridian altitude for solar longitude λ*. The underlying procedure is outlined (**Text 7**), and it is clear that the table displayed the function:

$$r(H^*) = \{ {}^{1}/_{15} \text{ arc Sin } [\text{ R Sin } 17° / \text{ Sin } H^*] \}^{snh} ,$$

for each degree of H* from 31° to 90° (the lower limit serves Tunis). The procedure is particularly ingenious because it is independent of terrestrial latitude and hence universal. (See also **VIa-4**, as well as **VIb-19** on the only other known universal table for twilight, from 16th-century Cairo.)

Closer inspection of numerous other Islamic twilight tables for various localities may well reveal that they also based on our formula.

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[3] See Zimmermann, "*Dustūr al-Munajjimīn*".
[4] This is to be interpreted as the latitude of the 4th climate (with ε = 23;35°—the accurate value is 36;22°) rather than necessarily related to any of the localities associated with the latitude in medieval geographical tables (which include Nishapur and Alamut)—see Kennedy & Kennedy, *Islamic Geographical Tables*, p. 690.
[5] See now Mestres, Zīj *of Ibn Isḥāq*, p. 65.

CHAPTER 6

FOUR KINDS OF UNIVERSAL INSTRUMENTS BASED ON THE FORMULA AND DESCRIBED BY AL-MARRĀKUSHĪ

6.0 General remarks on sundials

Most of the universal instruments described by al-Marrākushī and Najm al-Dīn are sundials; the remainder are graphic representations of our formula. Before I embark upon a description of various universal sundials designed by these two, a few general remarks about sundials are in order.[1]

Horizontal or vertical sundials normally serve a specific latitude. The horizontal sundials are usually fixed, but vertical sundials can be either fixed or movable so that they are in the solar plane or a perpendicular plane. Cylindrical or conical sundials facilitate the alignment to the sun, ensuring that the face of the instrument is always at the same angle to the horizon. A planar universal sundial can of necessity only be designed for the equatorial plane or the polar plane. Equatorial sundials are known from Antiquity and are described in several medieval Arabic texts.[2] Polar sundials appear for the first time—as far as I am aware—in the early 9th century; they are described in the treatise on sundial construction by pseudo-al-Khwārizmī or Ḥabash al-Ḥāsib, illustrated in **Fig. VIa-15.1**.[3] Any "universal sundial" fixed in a plane other than the equatorial or polar planes is bound to be based upon some approximate procedure. Two varieties not based on our formula are mentioned in **App. A1**.

In Book II of his *magnum opus*, al-Marrākushī describes three sundials and one grid, in each case as a supplement to a description of similar instruments marked for a specific latitude. To these we now turn. On those of Najm al-Dīn al-Miṣrī see **7**.

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[1] On sundials in Antiquity see Gibbs, *Greek and Roman Sundials*, and also Buchner, *Die Sonnenuhr des Augustus*. For a survey of Islamic gnomonics see Schoy, "Gnomonik der Araber" (long outdated) and my articles "Gnomonics" in *EHAS*, and "Mizwala" in *EI*$_2$, the latter repr. in King, *Studies*, C-VIII, and now **X-7** and Charette, *Mamluk Instrumentation*, pp. 145-208. On European sundials see, for example, Rohr, *Sundials*; and Zinner, *Alte Sonnenuhren* (contains catalogue). King, "Review of Higton", is a bibliographical essay on the history of fixed and portable sundials from Antiquity to the Renaissance.

[2] Equatorial dials are not mentioned in Gibbs, *Greek and Roman Sundials*, but one Hellenistic example, albeit cylindrical rather than planar, is described in Janin, "Un cadran solaire grec d'Afghanistan". Planar equatorial dials are described, for example, in the treatise of al-Maqsī (*fl.* Cairo, *ca.* 1275)—see King, "Astronomy of the Mamluks", p. 547.

[3] See King, "al-Khwārizmī", pp. 17-18 and 22, and Rosenfeld *et al*., eds., *Al-Khorezmi*, pp. 230-231.
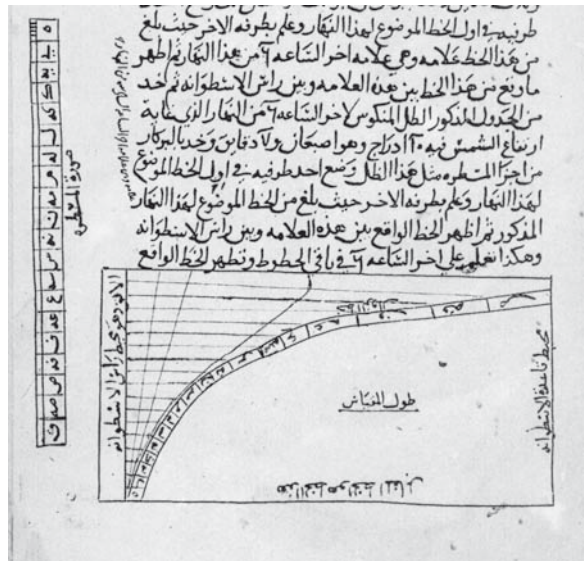
Fig. 6.1: al-Marrākushī's depiction of a universal cylindrical sundial. [From al-Marrākushī, *A-Z of Astronomical Timekeeping*, I, p. 235.]

6.1 The universal cylindrical sundial

In Ch. 4 al-Marrākushī describes the construction of a universal cylindrical sundial (*usṭuwāna*)—see **Fig. 6.1**.[4] For this he advocates using the table of vertical shadows z′(T,H), on which see **3.6**. I know of no earlier texts on cylindrical dials, but these must have existed already in 9th-century Baghdad because there is a treatise on a conical sundial—see **6.3**—from that time and place. I judge from the paucity of later Arabic texts and instruments that cylindrical dials were not widely used in Islamic astronomy. In fact Najm al-Dīn (**7.4**) is the only Muslim author of such a text who comes to mind. Bernard Goldstein has found a description of a cylindrical sundial in a text by Mordecai Comtino (*fl*. Constantinople, 15th century).[5] A single Ottoman dial, dating perhaps from the 18th century, is preserved in Istanbul (#7354).[6] The history of the cylindrical dial in Europe has been investigated,[7] but all of the known dials appear to serve specific latitudes.

6.2 The universal "locust's leg"

In Ch. 6 al-Marrākushī describes the construction of a universal vertical sundial based essentially on the same principle—see **Fig. 6.2**.[8] The instrument is called *sāq al-jarāda*, literally, "the locust's

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[4] See Sédillot-*père*, *Traité*, II, pp. 438-440.
[5] Goldstein, "Astronomical Instruments in Hebrew", p. 123.
[6] *Kandilli Instrument Handbook*, pl. 17.
[7] Thorndike, "Horologe of travelers"; Zinner, *Astronomische Instrumente*, pp. 50-51; and Kren, "Traveller's Dial".
[8] Sédillot-*père*, *Traité*, II, pp. 446-449.
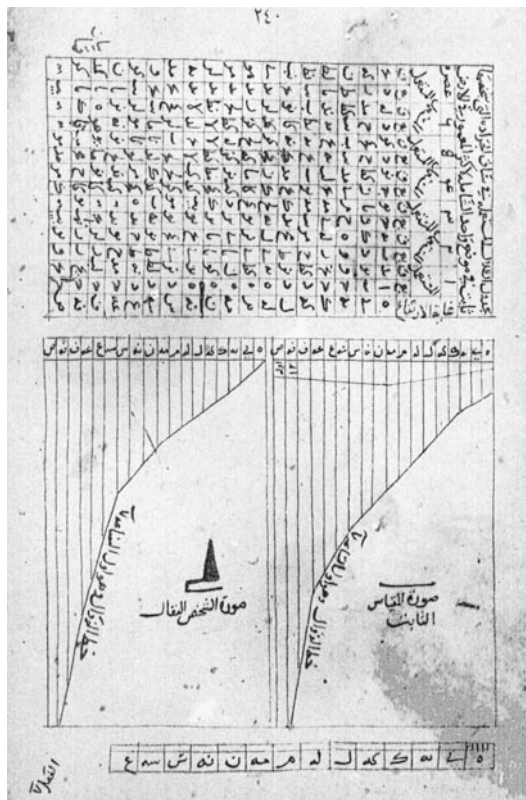
Fig. 6.3: al-Marrākushī's illustration of a universal conical sundial and a table for its construction. [From al-Marrākushī, *A-Z of Astronomical Timekeeping*, I, p. 244.]

Fig. 6.2: al-Marrākushī's depiction of a universal vertical sundial with a table for constructing its markings. [From al-Marrākushī, *A-Z of Astronomical Timekeeping*, I, p. 240.]

leg", on account of the general appearance of the markings. The name was used already in the 9th century for another astronomical device (**XIIa-C**), and there is no reason to doubt that such vertical sundials for specific latitudes were also in circulation in Baghdad at that time.

al-Marrākushī describes two varieties, with movable and fixed gnomons, respectively. Construction of the former can be achieved using the table of $z'(T,H)$, but for the latter the effective length of the gnomon is modified because the sun is no longer in the vertical plane through the gnomon. al-Marrākushī presents a table of a function $f(T,H)$ which he labels *al-ẓill al-mustaʿmal*, "the shadow used (in sundial construction)", a common term in Islamic gnomonics. The width of the sundial is to be 54 units compared with the gnomon length of 12, so that each 5° interval of H is 3 (= $^1/_4$ n) units wide. As Sédillot pointed out in a brief commentary, the function is defined by:

$$f(T,H) = {}^1/_{12} \bullet \sqrt{\{\, 12^2 + [\, {}^1/_5\,(90°–h) \bullet {}^1/_4\, n\,]^2 \,\}} \bullet z'(T,H)\ .$$

Only one sundial of this type has survived, this with a movable gnomon, made in Syria in the early 12th century and bearing markings for Damascus on one side and for Aleppo on the other.[9] Its existence proves—if proof were needed—that al-Marrākushī was not the inventor of this instrument.

[9] See Casanova, "Cadran solaire syrien"; *Paris IMA 1993-94 Catalogue*, pp. 436-437 (no. 332); and also **IV-7.4** and **XIVb-1**.

6.3 The universal conical sundial

In Ch. 8 al-Marrākushī describes the construction of a universal conical sundial based on our formula—see **Fig. 6.3**.[10] He presents a table of h(T,H) for T = 1, 2, ... , 6^{sdh} and H = 5°, 10°, ... , 90°, for this purpose, and describes how to use it to mark the surface of the sundial. The construction of such sundials has been discussed elsewhere and need not concern us here. The earliest description of a conical sundial for a specific latitude is from 9th-century Baghdad—see **4.1**, and two other early texts are also known.[11] However, no examples from the Islamic Middle Ages seem to have survived.

6.4 The "Fazārī balance"

Finally al-Marrākushī describes in Ch. 9 the construction of a compendium or multi-functional instrument called *al-mīzān al-Fazārī*.[12] The term *mīzān* generally means "balance", but it was also used to describe various early astronomical instruments for timekeeping by shadows.[13] al-Fazārī was an astronomer of the 8th century who together with Yaʿqūb ibn Ṭāriq (**2.2**) played an important role in the introduction of Indian astronomy in the Islamic world,[14] and it seems probable that at least parts of the instrument described by al-Marrākushī are due to him. The 10th-century bibliographer Ibn al-Nadīm attributes to him a treatise—now lost—entitled *Kitāb al-Miqyās li-'l-zawāl*, no doubt dealing with a device for determining midday by shadow lengths.[15]

The instrument under discussion was a kind of medieval slide-rule, but alas no examples survive. Only one other treatise on it, contemporary with al-Marrākushī and also from Egypt, is known to us.[16] The *mīzān* was in the form of a block with square cross-section whose length was about seven times its thickness. Four sets of markings were to be engraved on the four sides. Those on the second and fourth do not concern us here: the former consist of various trigonometric and declination scales, the latter of a two-dimensional declination and ascension grid. The markings on the first side can be for a specific latitude or universal. These are essentially the markings of a *sāq al-jarāda* described in **6.2**.

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[10] Sédillot-père, *Traité*, II, pp. 455-457.

[11] See Cheikho, "*al-Mukḥula*" (in Arabic); Wiedemann & Würschmidt, "Arabische kegelförmige Sonnenuhr"; Livingston, "Islamic Conical Sundial"; and now Charette, *Mamluk Instrumentation*, pp. 145-153.

[12] Sédillot-*père*, *Traité*, II, pp. 458-473 and figs. 80-84; Sédillot-*fils*, "Mémoire", pp. 46-55; and now Charette, *Mamluk Instrumentation*, pp. 163-164 and 222.

[13] Kennedy, *al-Bīrūnī's* Shadows, I, p. 155, and II, pp. 82-83, and also **IV-7.5**.

[14] On al-Fazārī see the article by David Pingree in *DSB*; Pingree, "al-Fazārī"; and Sezgin, *GAS*, V, pp. 216-217, VI, pp. 122-124, and VII, p. 101.

The word *fazārī* is here used as an adjective but there is no reason why it should not be the name of a person. Compare the similar usage in the expression *jadwal al-ẓill al-Khwārizmī*, "al-Khwārizmī's cotangent table", used by al-Marrākushī in MS Istanbul Topkapı A.III 3343, pp. 250-251 of the facsimile, corresponding to Sédillot-*père*, *Traité*, I, pp. 464-465. However, the relationship between this instrument and an 8th-century astronomer needs to be further investigated.

[15] Pingree, "al-Fazārī", p. 103, and Sezgin, *GAS*, V, p. 217, no. 2, and VI, p. 124, no. 5.

[16] *Cairo ENL Survey*, no. C24.

Those on the third side—see **Fig. 6.4a**—include a table of an auxiliary function for timekeeping and a graphical representation of the relationship between the shadows at midday and the shadows at the hours based on our formula. Two perpendicular axes are divided into 24 parts, one for the midday shadows and the other for the instantaneous shadows. The problem of representing very long shadows is handled in a very ingenious way by arranging that each scale be divided into two separate, but contiguous parts. The first scale serves $Z = 1, 2, \ldots, 12$, and then continues with $Z' = 12, 11, \ldots, 1$. The second serves $z' = 1, 2, \ldots, 12$, and then continues with $z = 12, 11, \ldots, 1$. The diagonal from $Z' = 0$ to $z = 0$ is drawn and labelled the meridian, since on it $z = Z$ or $z' = Z'$. An orthogonal grid is drawn for each unit of both axial scales.

al-Marrākushī explains how to mark the hour curves on the grid, but unfortunately the illustrations in the manuscripts I have consulted show no hour curves. The drawing of the latter is not without its problems because of discontinuities in the hour curves caused by the choice of arguments, but the grid is ingenious, and, from a mathematical view-point, of considerable historical interest.

For a discussion of the universal versions of the sundials known as *halazūn* and *ḥāfir*, which I had inadvertently omitted in my first study, I refer the reader to the available literature.[17]
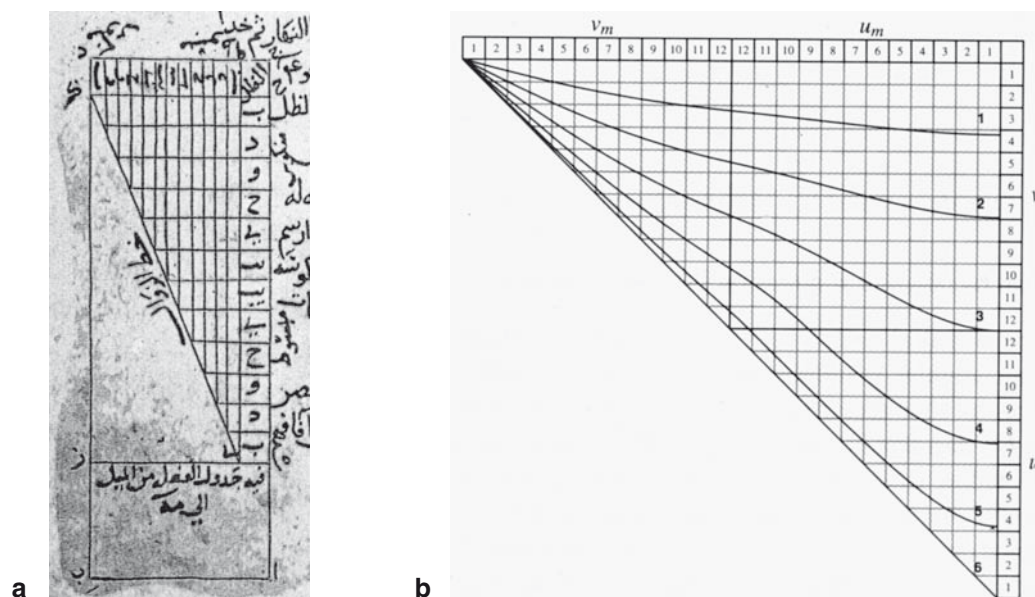
Fig. 6.4a: al-Marrākushī's grid for converting shadows. [From al-Marrākushī, *A-Z of Astronomical Timekeeping*, I, p. 253.]
Fig. 6.4b: Charette's reconstruction. [From Charette, *Mamluk Instrumentation*, fig. 3.35 on p. 164, courtesy of the author.]

[17] Sédillot-*père*, *Traité*, II, pp. 423-430, and Charette, *Mamluk Instrumentation*, pp. 153-160. See also de Vries *et al*., "Hafîr and Halazûn".

CHAPTER 7

FIVE KINDS OF APPROXIMATE UNIVERSAL SUNDIAL DESCRIBED BY NAJM AL-DĪN AL-MIṢRĪ

7.0 Introductory remarks

The values of h_i derived using the formula are reasonably accurate, but in the construction of a fixed horizontal or vertical sundial the azimuth of the shadow falling on the sundial also needs to be considered. **Fig. 7.0** shows the hour-lines for hours 1/11 and 2/10 (the most sensitive to change in latitude) on sundials superposed one upon the other for four specific latitudes that an Islamic universal sundial might aspire to serve. It is clear to a modern that each of these families of lines for a given hour can be approximated to by a mean. How well do the hour-curves on Najm al-Dīn's universal sundials 1 and 2 correspond to these optimal "means"? We now consider Najm al-Dīn's dials in some detail.[1]
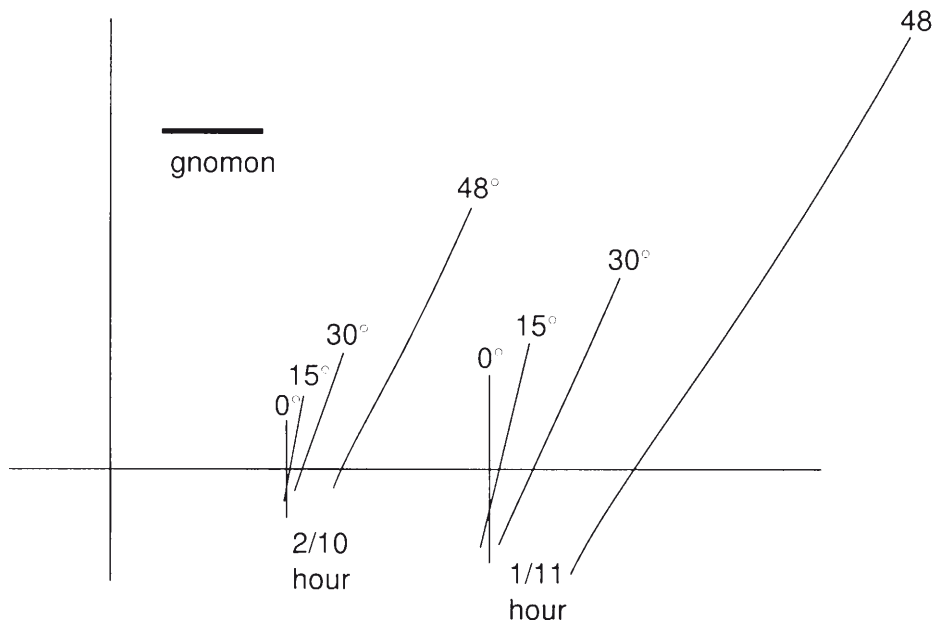
Fig. 7.0

[1] See also the new account of these instruments in Charette, *Mamluk Instrumentation*, pp. 160-166.

7.1-3 Three universal horizontal sundials

7.1 The construction of the first horizontal sundial (Ch. 61) is as follows—see **Figs. 7.1a-b**. Draw an arc ANB, two-thirds of a circle ANBS, with radius 72 units about the base of the gnomon (length 12) at O cutting the meridian NOS at N and S. (In the text nothing is said about this radius but the illustration indicates that it is about double the length of the maximum meridian shadow, 36.) Then draw an arc AOB centre S with the same radius. Mark midday shadows from 0 to 36 on the meridian ON and draw a straight line CUD perpendicular to the meridian at S = 36 (U) to cut the arc ANB at C and D. Then the arc AOB and the line CUD are the *madār*s for Z = 0 and Z = 36. The term *madār* is difficult to translate in this context; usually it means "day-circle", and, at a stretch of the imagination, "shadow trace", but here it is best rendered "the curve/line corresponding to - ". For Z = 0 and 36 mark off z_i from the table of $z_i(Z)$ (**3.6a**) on both sides of the meridian cutting the arc AOB and the line CUD, respectively. Connect corresponding pairs of intersections by straight lines: these are to be the hour-lines. Then construct the *madār*s for each 3 units of Z by joining the points of intersection of the shadows z_i with the hour-lines; these curves represent curious, irregular developments between an arc of a circle and a straight line. The curve for the *ʿaṣr* is drawn through the intersections of shadows length $h_a(H)$ with the *madār*s for each 3° of H.

The result of this construction at first sight resembles a regular horizontal sundial. The hour lines are analogous, but the arc AOB and the straight line CUD are clearly only crude approximations to the hyperbolae that are the actual shadow traces for specific values of Z. The shape of the *madār* for Z = 0 was clearly devised in order to pull the markings of the sundial south of the gnomon. The assumption that the hour-curves are straight lines is unjustified. See further the concluding remarks below.

7.2 Different definitions of the *madār*s for the values of Z lead to a rather different-looking sundial as the second example, which Najm al-Dīn seems to prefer (Ch. 62); the markings are intended for one side of the *mīzān al-Fazārī* **(6.4)**. Here they are all taken as straight lines perpendicular to the meridian. By marking the shadow lengths $z_i(Z)$ from the same table on the *madār*s for Z and connecting corresponding points one obtains the charming family of hour-curves shown in **Fig. 7.2a** and the reconstruction in **Fig. 7.2b**. This time the *ʿaṣr*-curve is constructed by marking z_a on each of the *madār*s shown in the figure and joining these markings. See further the commentary below.

7.3 The third horizontal universal sundial (Ch. 63: see **Fig. 7.3a**) is in the form of a quadrant, a gnomon being attached at the centre perpendicular to the plane of the instrument. The meridian altitude is marked on the scale of the quadrant, and the radii corresponding to each 10° of meridian altitude (again called *madār*s) are drawn. From the accompanying table of $z_i(H)$ the shadows for each hour are measured on the appropriate radius for H, and the hour-curves are then constructed—see **Fig. 7.3b**. To use the quadrant, one must rotate it in the horizontal position until the vertical plane passing through the sun and the observer intersects the quadrant in the radius of the appropriate solar meridian altitude; the time can then be estimated from the hour-curves. The *modus operandi* is not mentioned in the text: with Najm al-Dīn it never is.
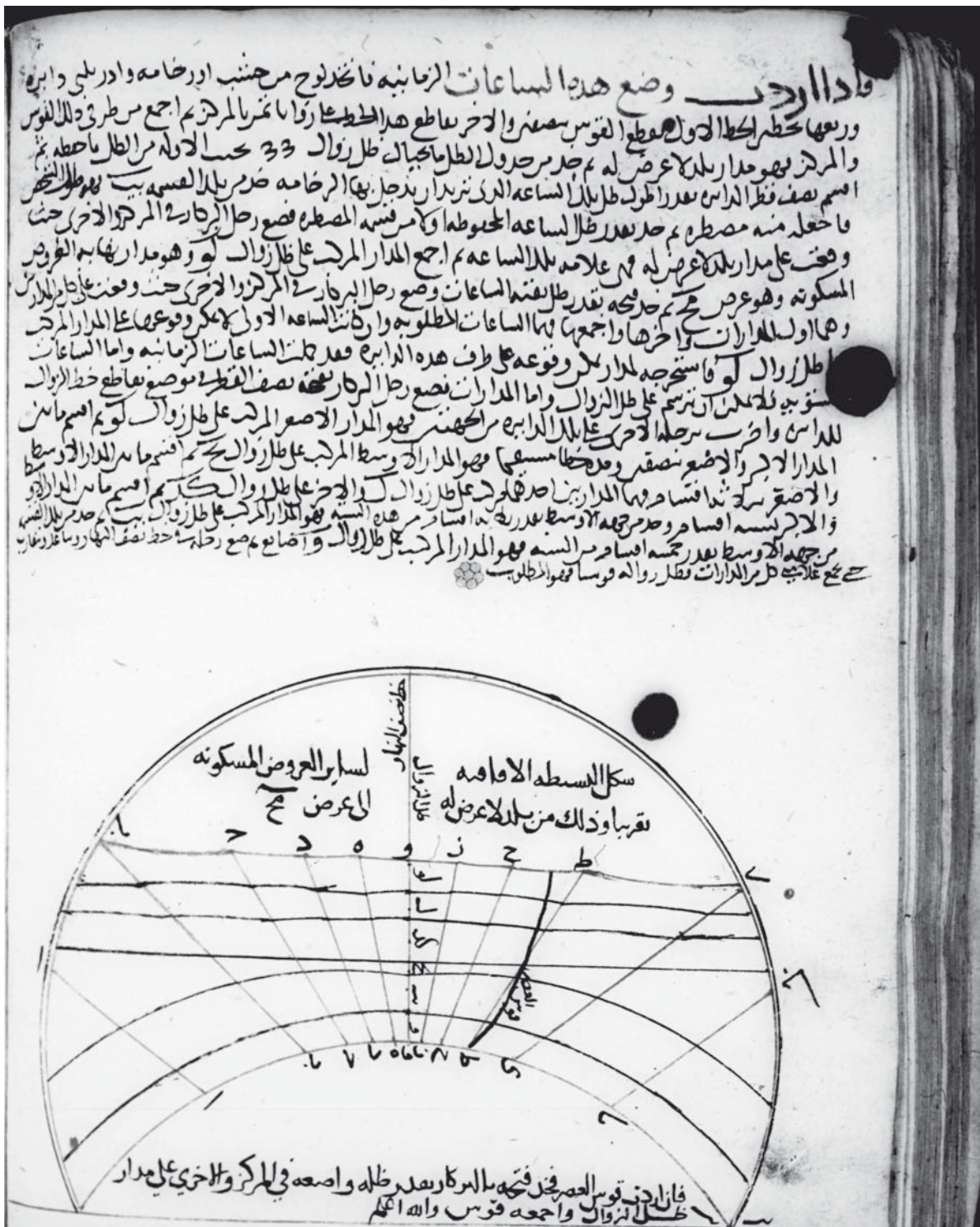
Fig. 7.1a: The first universal sundial of Najm al-Dīn al-Miṣrī. [From MS Dublin CB 102,2, fol. 77v, courtesy of the Chester Beatty Library.]
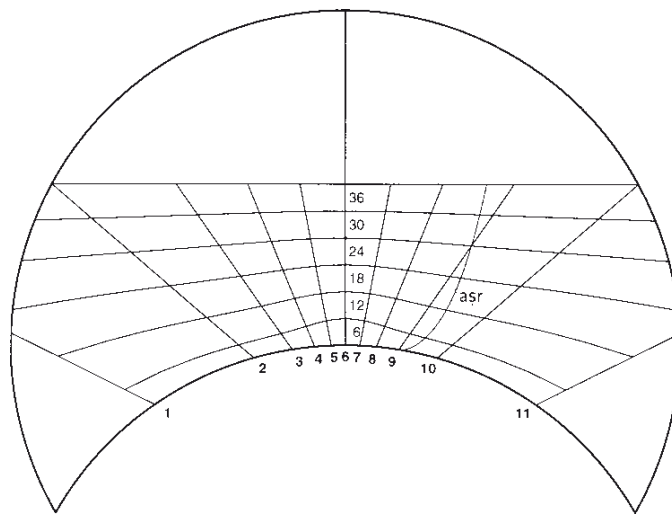
Fig. 7.1b: Charette's reconstruction. [From Charette, *Mamluk Instrumentation*, fig. 3.37, courtesy of the author.]
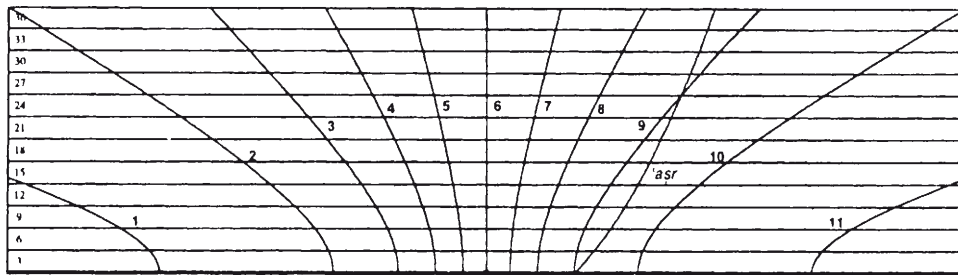
Fig. 7.2b: Charette's reconstruction. [From Charette, *Mamluk Instrumentation*, fig. 3.36, courtesy of the author.]
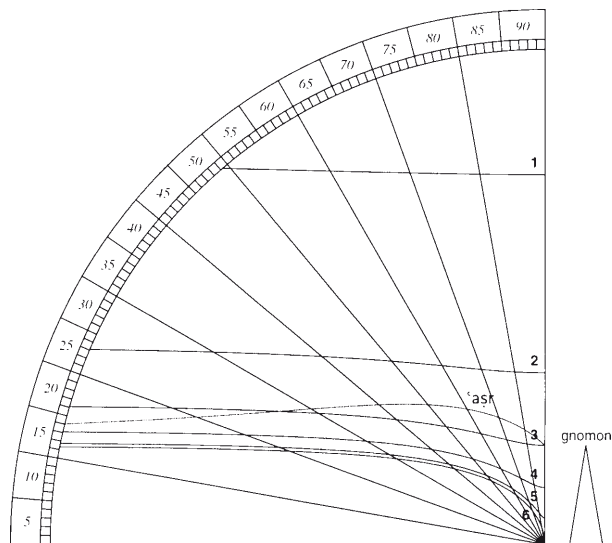
Fig. 7.3b: Charette's reconstruction. [From Charette, *Mamluk Instrumentation*, fig. 3.31, courtesy of the author.]
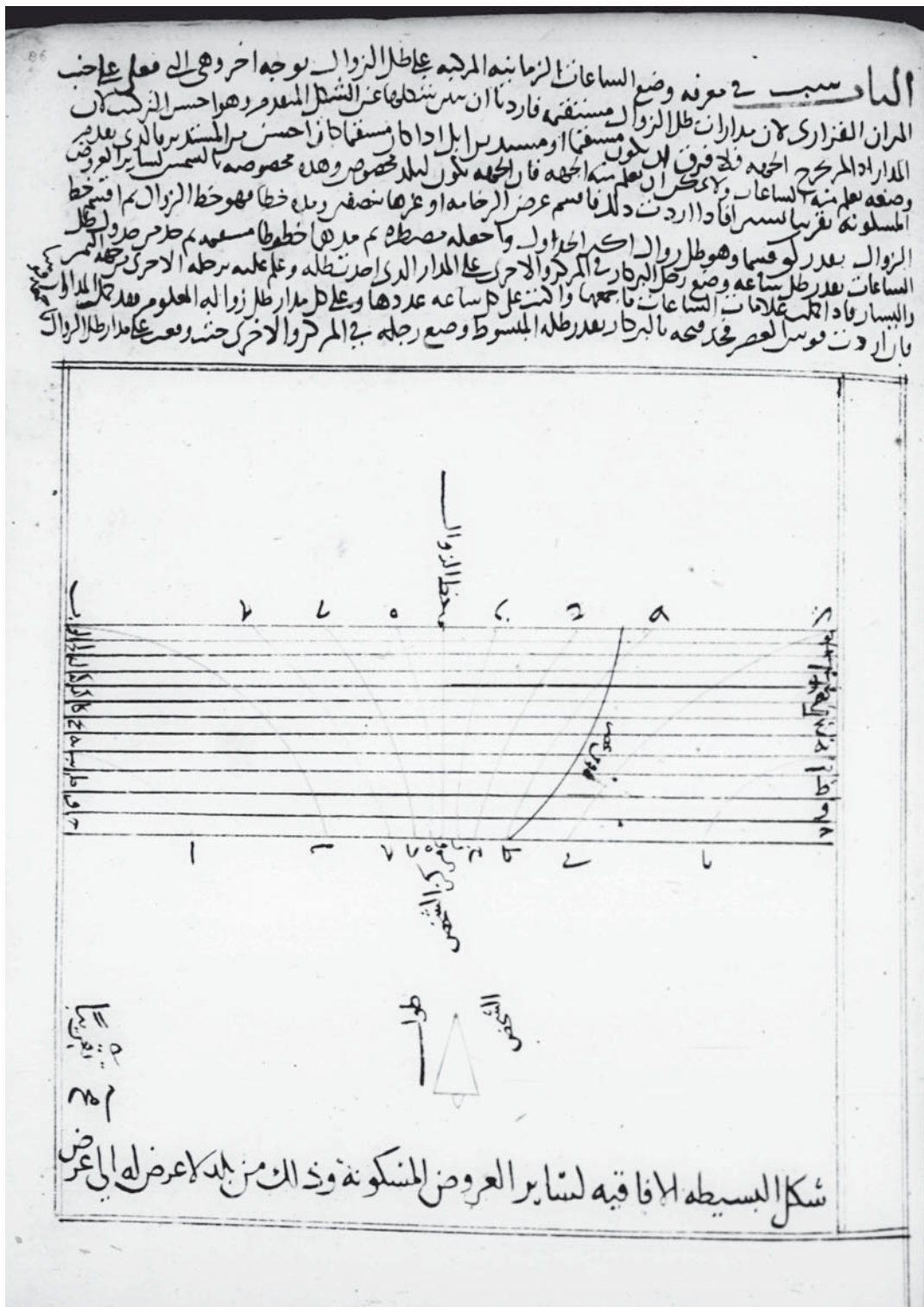
Fig. 7.2a: The second universal sundial of Najm al-Dīn al-Miṣrī. [From MS Dublin CB 102,2, fol. 86r, courtesy of the Chester Beatty Library.]

Fig. 7.3a: The third universal sundial of Najm al-Dīn al-Miṣrī, from which the curve for the 1st hour has inadvertently been omitted. [From MS Dublin CB 102,2, fol. 86v, courtesy of the Chester Beatty Library.]

One problem with the instrument is the adoption of a quadrant to bear the markings; preferable would have been a rectangle around the hour-curves, with the meridian altitude measured (non-linearly) along the upper longer side. As it is, the markings for the hours, regardless of the scale used, crowd near the bottom part of the quadrant. The hour-lines shown in the diagram in the Chester Beatty manuscript are quite distorted; an accurate representation is shown in **Fig. 7.3b**. The instrument cannot be deemed a success, but Najm al-Dīn obviously could not resist including it, probably because—viewed mathematically—it indeed represents a valid graphical representation of the approximate formula. I now turn to his two vertical dials.

7.4-5 The two universal vertical sundials

Najm al-Dīn also describes two sundials that are universal.[2]

7.4 To generate the markings on the first vertical sundial (Ch. 64: see **Figs. 7.4a-b**) we use the accompanying table of $z'_i(H)$ (**3.6d**). The sundial is rectangular, the horizontal scale on the
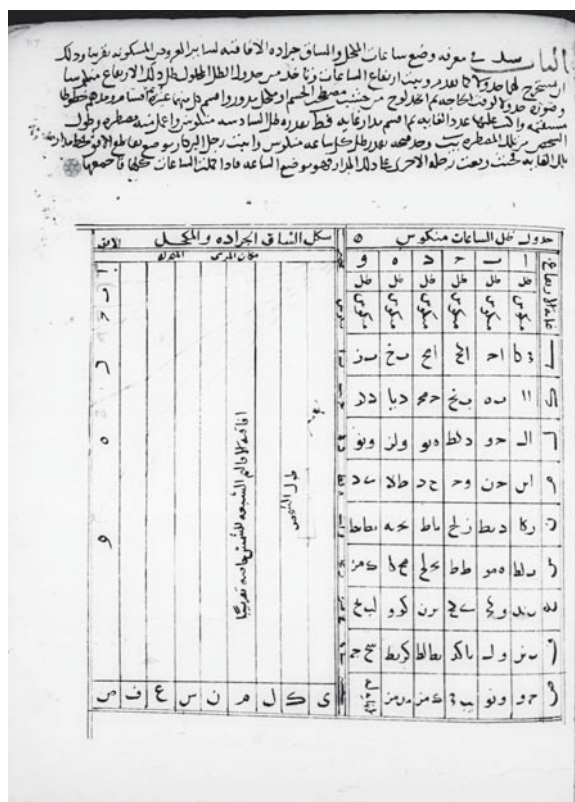
Fig. 7.4a: The first universal vertical sundial of Najm al-Dīn al-Miṣrī. [From MS Dublin CB 102,2, fol. 87r, courtesy of the Chester Beatty Library.]
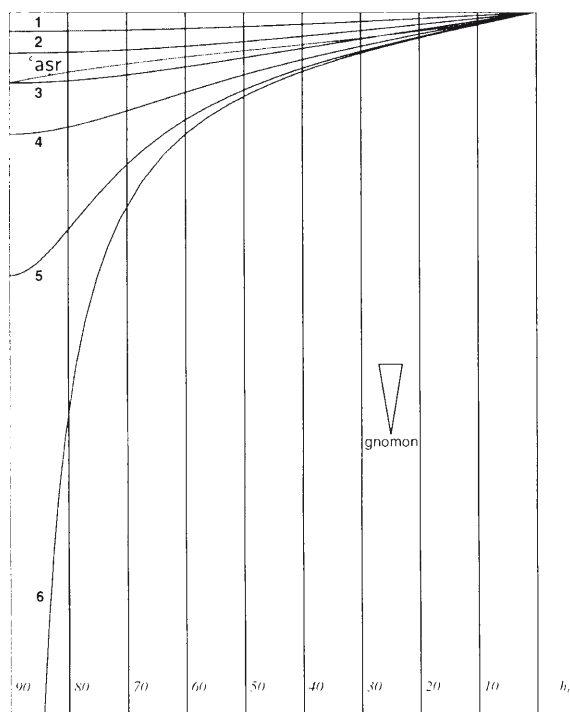
Fig. 7.4b: Charette's reconstruction. [From Charette, *Mamluk Instrumentation*, fig. 3.23, courtesy of the author.]

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2 See now *ibid.*, 3.2.1 and 3.1.3.

shorter upper side serving Z. For each 10° of H vertical lines are drawn, the values of $z'_i(H)$ from the table are marked off, and the "hour-curves" are drawn. From the names of the sundial (*mukḥula* and *sāq al-jarāda*) and its function we infer that it can either be cylindrical in shape or plane. An inscription on the figure confirms that the gnomon is movable. This sundial gives the time precisely according to the formula because the gnomon is placed on top of the marking corresponding to H on the day in question. The problem of azimuth is therefore eliminated. (For any given latitude only about one-half of the horizontal scale is used.) These two versions of the instrument, if such were intended, correspond to two of al-Marrākushī's instruments (**7.1** and **7.2**).

7.5 The second vertical sundial proposed (Ch. 76: see **Fig. 7.5a**) is a combination of an observational and a calculating device. It is to be constructed using a table of $h_i(H)$ given in the same chapter (**3.6b**). The frame of the instrument is a square and it is bisected by a diagonal. A quadrant marked with a uniform scale of 0° to 90° is drawn within one half of the square with centre at the upper left corner: this represents a scale for h. A gnomon of 12 units length is positioned in the centre of the quadrant perpendicular to the plane of the instrument. The lower border of the square is divided linearly for each 5° of H. Each division on the scale is joined with
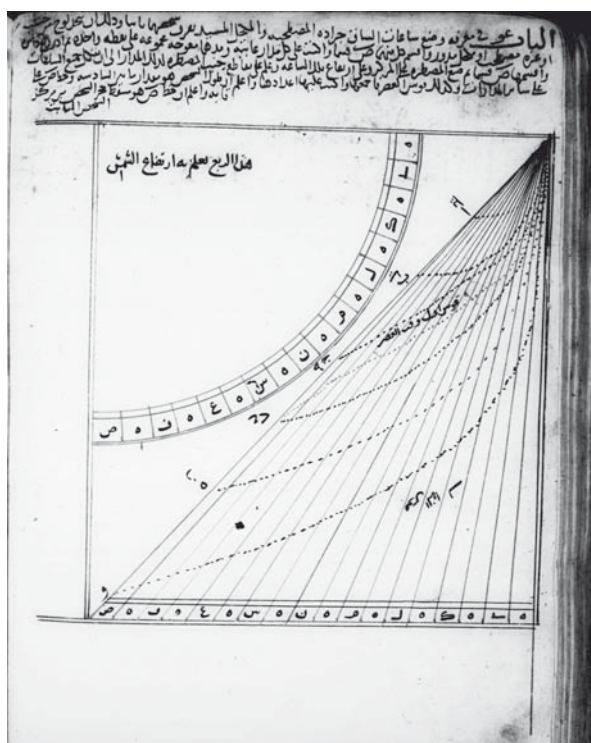
Fig. 7.5a: The second universal vertical sundial of Najm al-Dīn al-Miṣrī. [From MS Dublin CB 102,2, fol. 93v, courtesy of the Chester Beatty Library.]
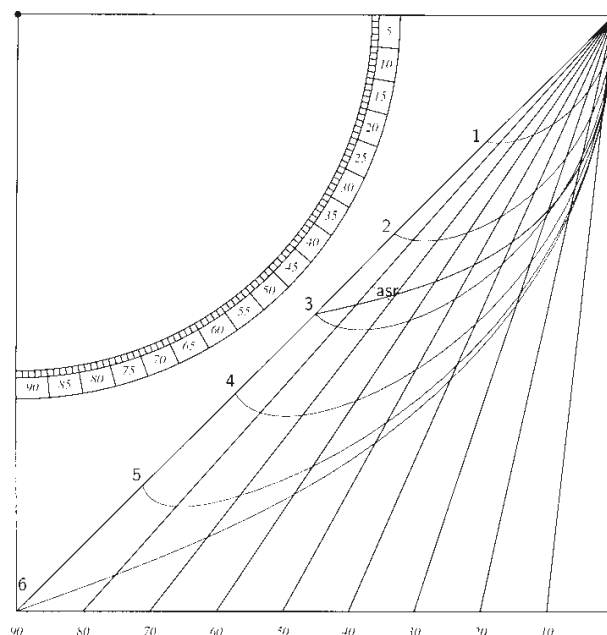
Fig. 7.5b: Charette's reconstruction. [From Charette, *Mamluk Instrumentation*, fig. 3.19, courtesy of the author.]

the upper right corner by a straight line. Onto this grid the hour-curves are constructed by feeding in H in the lower straight scale and the $h_i(H)$ from the table in the quadrant scale and joining corresponding points from the centre down to the positions corresponding to h = H on the diagonal.

The sundial must be held vertically in the plane of the sun to measure H and h on the quadrant scale. Then the intersection of the shadow of the gnomon at altitude h with the appropriate *madār* for H relative to the "hour-curves" yields the time. Whilst this sundial gives "correct" results in theory, a serious disadvantage underlies its design. The curves are in fact not so nicely distributed over the *madār*s as in **Fig. 7.5a**—see the reconstruction in **Fig. 7.5b**. Again the scale representing H and the corresponding *madār*s are arbitrarily designed; in this particular configuration the hour-curves get so close for $h_i < 30°$ that the sundial becomes impractical for these solar altitudes. It may be that this grid was inspired by the one advocated by al-Marrākushī for the "Fazārī balance"—see **6.4**.

7.6 Concluding remarks

These then are the five sundials of Najm al-Dīn. The last three are, at least in theory, neither better nor worse than the approximate formula itself. But unfortunately he has implicitly imposed an arbitrary azimuth upon the shadow lengths z_i used in dials 1 and 2, and since the resulting hour-lines lie nowhere near the optimum "means", both must be deemed unsuccessful. Of course, both grids could be used as sundials to find the time according to the approximate formula, assuming that one could incline them to the meridian by appropriate amounts as the day progressed. Dial 2 can be considered as providing a mathematical grid from which one can read off $z_i(Z)$, but in the case of 1—where Najm al-Dīn has made a deliberate effort to make the ensemble look like a sundial—the resulting grid cannot even be used for this purpose.

In brief, Najm al-Dīn risked his reputation by describing the first two horizontal dials; to his credit he did say that he preferred the second. But most probably neither of them—nor any of the more successful, last three dials—was ever made, let alone used. There were plenty of accurately-constructed sundials available in Egypt and Syria *ca*. 1300 for those who appreciated such exotica (**X-7.2**) as well as several facile arithmetical shadow schemes for those who, like the scholars of the sacred law, had no time for trigonometry, mathematical tables, or astronomical instruments (**III**).

CHAPTER 8

THREE INSTRUMENTS FOR TIMEKEEPING USING THE FORMULA

I now distinguish between instruments with and without special markings for the seasonal hours.[1] The former are treated in **9** and **10**.

8.1 The trigonometric quadrant of al-Khwārizmī

MS Berlin Ahlwardt 5793, fols. 96v-97v (**1.3.1**), contains a short text, most probably by al-Khwārizmī, on the use of a quadrant for finding T(h,H) with our formula.[2] The quadrant bears no markings for the hours, and it is to be regarded as an early form of trigonometric quadrant. It appears that the formula inspired the instrument. The text (**Text 2**) informs us that the quadrant has uniform altitude and axial scales (0°-90° and 0-150, respectively), lines drawn parallel to the base for regular divisions of the altitude scale and concentric circles about the centre for regular intervals on the axial scale. **Fig. 8.1a** shows an illustration of this variety of quadrant (with radius 60 units) from a Persian treatise on the astrolabe written about 1450 in Herat.[3]

To use the instrument—see **Fig. 8.1b**—mark AD = H and, using the parallel for H (= CD), measure the corresponding Sine (= OC) on the axis OB. Set the marker at C so that OC = Sin H and move the thread to OMX so that the marker at M lies on the parallel of h (= EF). Then AX = T. In **Fig. 8.1a** the dark lines show a worked example for H = 42°, h = 32°, the result being T = 50° (= 4;20^{sdh}). Computation yields 52;22. The "correct" result would of course depend on the latitude of the locality.

Both al-Marrākushī[4] and Najm al-Dīn (Ch. 58: see **Fig. 8.1c**) mentioned this variety of trigonometric quadrant (*al-rubʿ al-mujayyab*). Various modifications were made to it over the centuries. The most common variety in the late medieval period (properly called *rubʿ al-dustūr*), which was well suited for finding the time using the accurate formula, bore an orthogonal grid resembling modern graph paper and fitted with one or two semi-circles on the axis for facilitating trigonometric operations—see **Figs. 8.1d** and **11.3a**.[5] I do not know when these

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1 Some of the material in this and the next section was originally taken from an unpublished study on the early history of the quadrant.

2 See already King, "al-Khwārizmī", pp. 28-29, and now Charette & Schmidl, "al-Khwārizmī on Instruments", pp. 179-181.

3 *Cairo ENL Survey*, no. G41, and pl. LIVb on p. 274; and King, *op. cit.*, p. 28.

4 Sédillot-*fils, Mémoire*, pp. 82-87, and fig. 11.

5 On this sine quadrant, properly called *rubʿ al-jayb al-sittīnī*, see Schmalzl, *Geschichte des Quadranten*, pp. 83-99; Würschmidt, "Gedosi über den Quadranten"; and King, "al-Khalīlī's Qibla Table", pp. 109-115. More recently, we have learned that such quadrants featured already on the astrolabe and equatorium (*zīj al-ṣafāʾiḥ*) of the 10th-century scholar Abū Jaʿfar al-Khāzin: see **Figs. X-6.1** and **Figs. XI-6.1.1-2**. On the tradition of this instrument in medieval Europe see Poulle, "Sexagenarium".
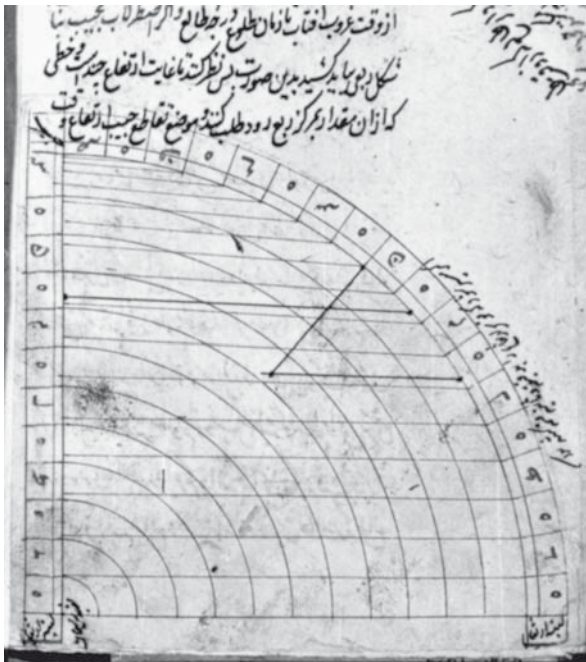
Fig. 8.1a: An illustration of a sine quadrant in which the procedure for a worked example of the operation to find T(h,H) is specifically demonstrated. [From MS Cairo S 4792, fol. 114v, courtesy of the Egyptian National Library.]
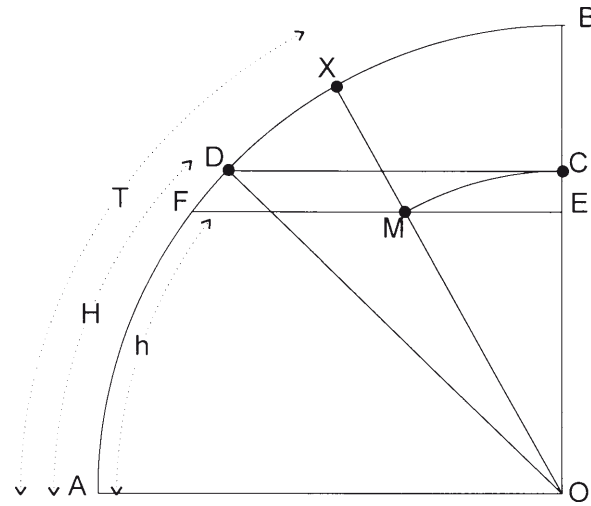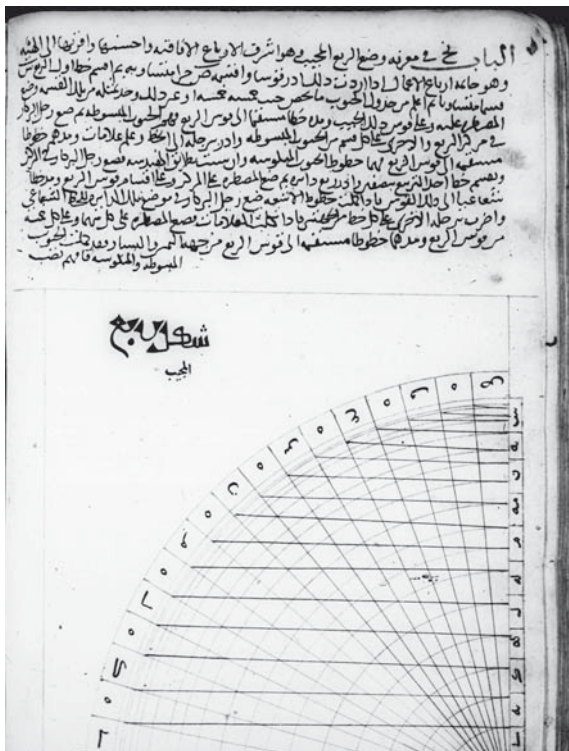
Fig. 8.1b
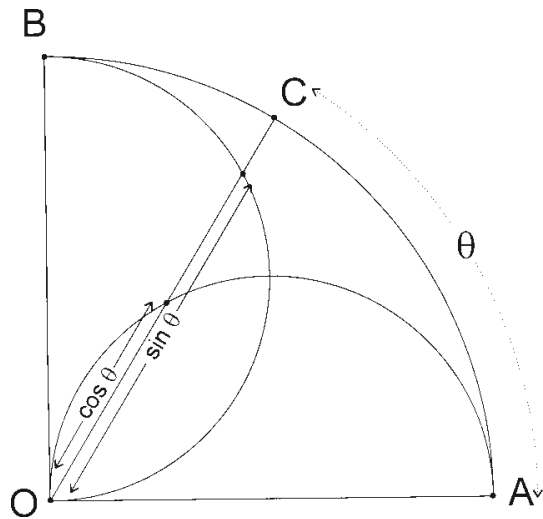
Fig. 8.1d: With two axial semicircles a single setting of the thread at an arbitrary argument θ can enable the user to set the bead at either Sin θ or Cos θ immediately. See further **Fig. 11.3a**.

←
Fig. 8.1c: Najm al-Dīn al-Miṣrī's sine quadrant with a set of parallels for the sines of each 5°, together with a corresponding set of quarter-circles, and a set of radial markings. [From MS Dublin CB 102,2, fol. 75v, courtesy of the Chester Beatty Library.]
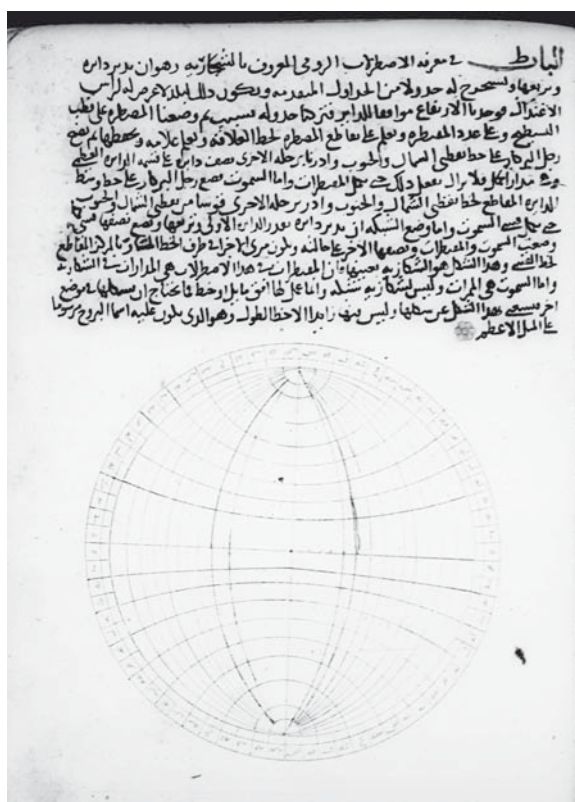
Fig. 8.2a: The *shakkāziyya* plate illustrated in Najm al-Dīn al-Miṣrī's treatise. [From MS Dublin CB 102,2, fol. 80r, courtesy of the Chester Beatty Library.]

auxiliary semi-circles were first introduced for this purpose, but the principle was clearly already known to the inventor of the horary quadrant described in **9.1**.

8.2 The *shakkāziyya* plate and associated quadrant

The second instrument of this kind, the *shakkāziyya*, was not designed specifically to solve our formula. Rather it was conceived as a universal astrolabic grid, with which one can perform a variety of operations. One of these—the determination of T(h,H)—can only be achieved approximately.

The origins of the name *shakkāziyya* are obscure. It first appears in the writings of Ibn al-Zarqālluh on the universal *shakkāziyya* and *zarqālliyya* plates, yet there seems also to be a connection with his contemporary in 11th-century Toledo, ʿAlī ibn Khalaf, known as al-Shajjār, who invented a universal astrolabe with two *shakkkāziyya* parts.[6] Especially the latter realized

[6] See King, "Universal Astrolabe"; my article "Shakkāziyya" in *EI*$_2$; also Puig, *Al-Šakkāziyya*, esp. p. 26.

that a grid of *shakkāziyya* markings rotating over a plate of similar markings can be used to convert coordinates from any orthogonal system of spherical coordinates to any other. The problem of converting between coordinates in the equatorial system (T,δ) and those in the horizon system (h,a) is just one example: it suffices to incline the meridian axis of the grid to the meridian axis of the plate at an angle equal to the local latitude ϕ.[7]

Ibn al-Zarqālluh (**2.1**) dispensed with the rete of this instrument and in so doing dispensed with part of its utility. In one (the first?) version of his instrument, called the *zarqālliyya*, he superposed two sets of *shakkāziyya* markings whose axes were inclined at an angle equal to the obliquity of the ecliptic ε, so that the instrument (when fitted with an appropriate alidade) is only suited for converting ecliptic and equatorial coordinates. In another, simpler, version (the second ?), labelled the *shakkāziyya*, he used a single set: see **Fig. 8.2a**. When this grid is used with a rectilinear alidade, the determination of T(h,H) is approximate; indeed, it depends upon our formula. (There is a second method that operates with an iterative "trial and error" procedure.[8])

Ibn al-Zarqālluh was well aware of this deficiency, and in both of his treatises on slightly different varieties of his plate (Arabic: *ṣafīḥa*; European: *azafea*, *etc*.) he pointed it out. (He also compiled a different treatise on the same plate with and alidade and movable perpendicular *brachiolus*, in which the derivation of t(h,δ,ϕ) is exact. A single example of this kind of cursor is known to survive.[9]) His observation about the approximate nature of the operation with a simple alidade was recorded in each of the Hebrew, Middle Castillian, and Latin translations of his treatise.[10] Ibn al-Sarrāj, in the short treatise extant in Princeton, mentions a quadrant with a set of *shakkāziyya* declination curves which serves as a variety of trigonometric quadrant.[11] When this instrument, fitted with a thread and movable bead, the procedure for finding T(h,H) is identical to that described above. Various Muslim astronomers in 14th-century Syria and Egypt also favoured this instrument.[12]

The markings consist of meridians and day-circles represented as arcs of circles. Only the latter are used for reckoning the hours, and the following is a modern interpretation—see **Fig. 8.2b**: the day-circle for any argument θ measured on the circular scale is an arc of a circle radius cot θ whose centre is at distance cosec θ from the centre of the quadrant on the vertical axis.[13] To find T(h,H) set the bead at C in **Fig. 8.2c**, the intersection of the day-circle CD for argument H with the vertical axis, and then move the thread to the position OMG in which the bead at M lies on the day-circle EF corresponding to argument h: the thread marks off T on the circular scale, that is, AX = T. This procedure defines T as with our formula.

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[7] On the solution of problems of spherical astronomy with such a double grid see King, "Universal Quadrant of al-Māridīnī".

[8] Puig, *Al-Šakkāziyya*, ch. 18; also Michel, *Traité de l'astrolabe*, p. 101. See also Plofker, "Iterative Approximations".

[9] Puig, *Azafea de Azarquiel*, pp. 30 and 64-65.

[10] Puig, *Al-Šakkāziyya*, p. 33 (Arabic); and Millás Vallicrosa, *Don Profeit Tibbón sobre l'assafea*, pp. 27 (Hebrew), 70 (Middle Castillian), and 126 (Latin). That the derivation of T(h,H) using the *saphea* was equivalent to its derivation using the universal horary quadrant was noted already in Tannery, "*Quadrans vetus*", A, and B, p. 147.

[11] *Princeton Catalogue*, p. 419; and Charette, "Der geflügelte Quadrant", p. 34.

[12] See Samsó & Catalá, "Cuadrante *šakkāzī*", and Samsó, "Cuadrante *šakkāzī*", based on various Egyptian treatises.

[13] See already North, "Meteoroscope", p. 60, and King, "Universal Quadrant of al-Māridīnī", pp. 231-232.
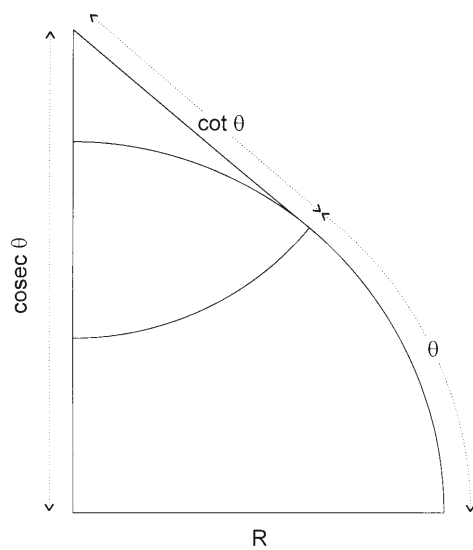
Fig. 8.2b
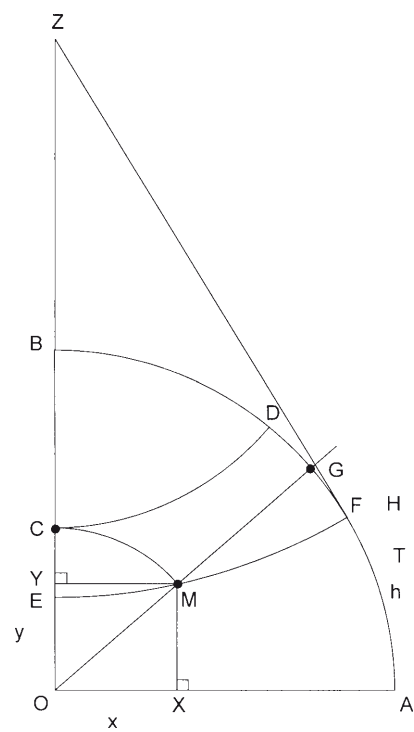
Fig. 8.2c
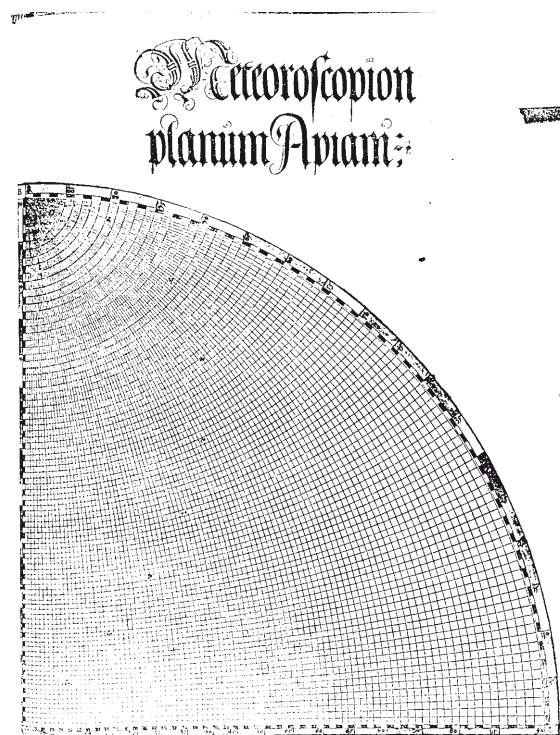
Fig. 8.2d: The plane meteroscope as illustrated by Peter Apian. [From Apian, *Astronomicum Caesareum*, 1540, also in North, "Meteoroscope".]

It is not clear how widely the *shakkāziyya* quadrant was used in the Islamic world. Only one example survives, from the Mamluk period, made by Abū Ṭāhir *ca*. 1345, and bearing a curious combination with a trigonometric quadrant (see **Fig. 8.2e**).[14] However, at least a dozen treatises in Arabic, Persian and Turkish were written on the simple *shakkāziyya* quadrant between the 14th and the 19th centuries.

This quadrant was popular in Europe, where it was sometimes called the "meteoroscope" (for what reason is not apparent); there it was used for the general solution of right-angled spherical triangles.[15] **Fig. 8.2d** shows the instrument as illustrated by Peter Apian (b. 1495, *fl*. Ingolstadt, d. 1552),[16] and a fine example by Antonio Magini (Bologna, 1555-1617) is preserved in the Museum of the History of Science in Oxford.[17] The same instrument though was already popular in Egypt and Syria in the 14th century.
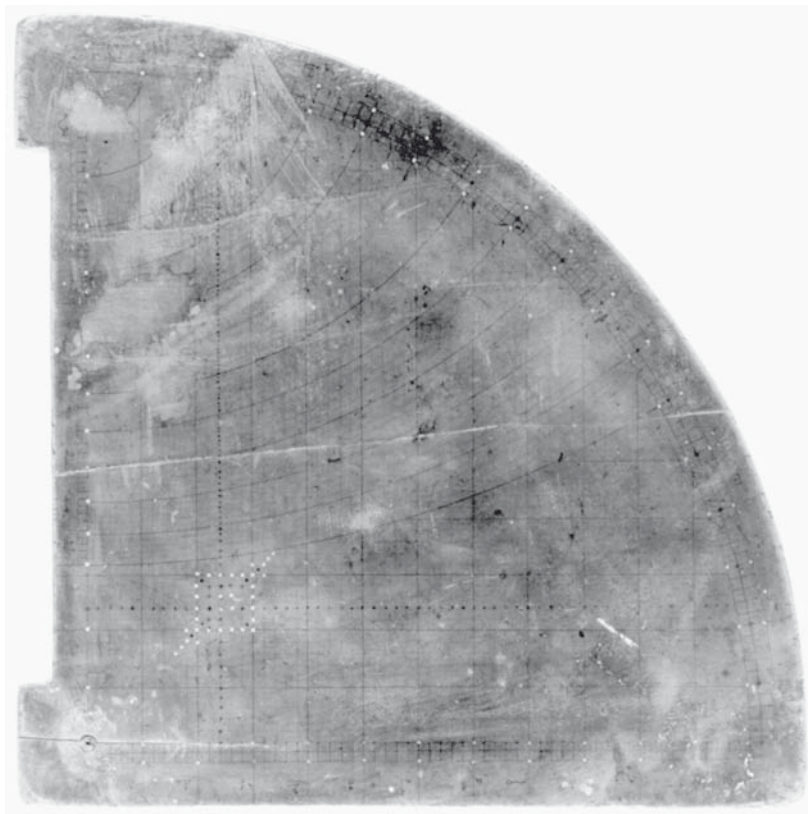
Fig. 8.2e: The most unusual markings on the back of a quadrant by Abū Ṭāhir (#5010). I do not know how they were supposed to be used. The same holds for the astrolabic markings on the other side (see **Fig. V-9.3**). [Courtesy of the Chester Beatty Library, Dublin.]

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[14] #5010—Dublin, Chester Beatty Library, inv. no. MS 4—unpublished; see **Fig. V-9.3** for an illustration of the other side of this piece.

[15] The European tradition is discussed in North, "Meteoroscope". On the name as applied by Ptolemy and in Europe from the 16th to 18th century see *ibid*., p. 57.

[16] On Apian see the short article by George Kish in *DSB*, and new book Röttel, ed., *Peter Apian.*
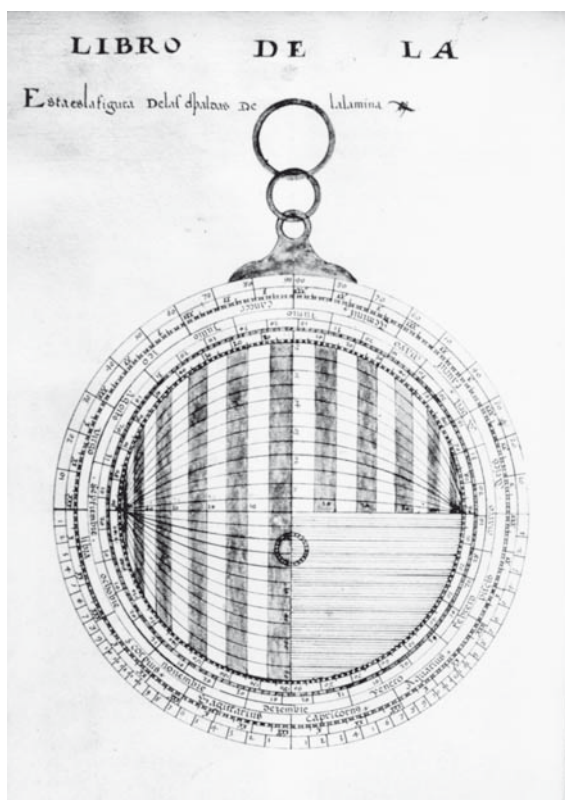
Fig. 8.3a: The back of Ibn al-Zarqālluh's *ṣafīḥa* or *lamina*, as illustrated in the *Libros del saber*. See also **Fig. XIIb-16a**. [Courtesy of Prof. Julio Samsó, Barcelona.]
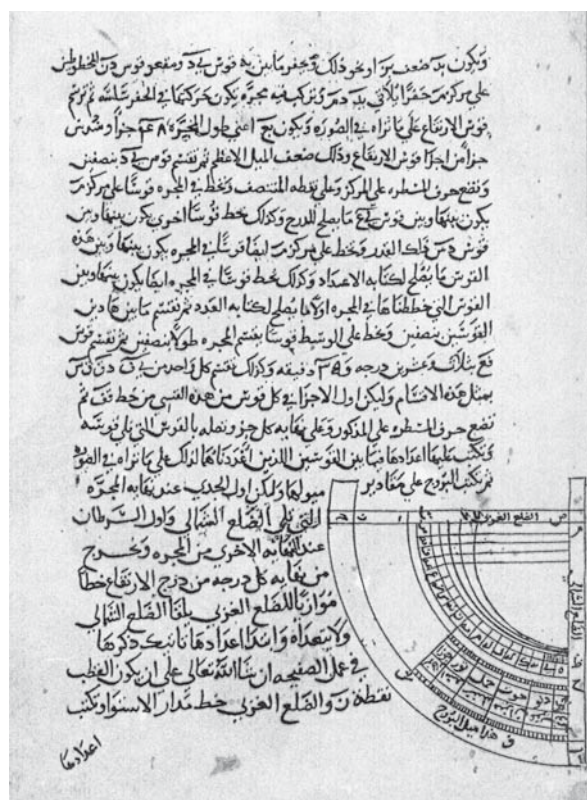
Fig. 8.3b: al-Marrākushī's diagram of a trigonometric quadrant with a movable cursor. [From al-Marrākushī, *A-Z of Astronomical Timekeeping*, II, pp. 376.]

8.3 The *zarqāllī* quadrant

On the backs of several Western Islamic universal plates of the variety known as *zarqālliyya* after Ibn al-Zarqālluh (**8.2**), there is a quadrant of special markings. On some *zarqālliyya*s there are actually three quadrants out of four bearing markings of this kind—see **Fig. 8.3a**.[18] These features are not mentioned in the published versions of the various treatises on the *zarqālliyya*.[19]

Two centuries after Ibn al-Zarqālluh devised his plate al-Marrākushī mentioned these markings in two contexts, firstly in describing the back of the *zarqālliyya* and secondly in describing what he called *al-wajh al-jaybī min al-rubʿ al-zarqāllī*, "the trigonometric grid side of the *zarqāllī* quadrant". In this second context the grid bears a cursor—see **Fig. 8.3b**. al-Marrākushī asserts that it is a variety of trigonometric quadrant and does not go into any detail, although he implies that some of the operations which can be performed with it are approximate (*wa-fīhi umūr yasīra*).

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[17] Illustrated in *Santa Cruz 1985 Exhibition Catalogue*, pp. 104-105.

[18] See Millás, *Azarquiel*, pl. VIII opposite p. 433; and *Santa Cruz 1985 Exhibition Catalogue*, pp. 94-95.

[19] They have been studied in Puig, "La proyección ortográfica en el Libro de la açafeha", and, more recently, *eadem*, "Ibn al-Zarqālluh's Orthographic Projection".

CHAPTER 9

VARIETIES OF EARLY UNIVERSAL HORARY QUADRANTS

9.0 Introductory remarks

In this section I describe four basically different kinds of horary quadrants—that is, with markings for each seasonal hour—each based upon the same principle, namely, the approximate formula. In each one feeds in H and h and reads off T^{sdh}. The first three date from the 9th century if not before, and the last, attested only in a 12th-century Andalusī treatise, was probably developed not much later than the others. The anonymous Abbasid treatise in the first Cairo manuscript mentioned below also states that a movable cursor can be fitted to any of these quadrants—see further **9.6**.

9.1 The horary quadrant with circular arcs (type a)

MS Cairo DM 969,4 (**1.3.2**) is devoted mainly to operations with an horary quadrant with the hour-curves marked as arcs of circles through the centre of the quadrant and partly covered by the markings of a shadow-square. This variety of quadrant was particularly popular on the backs of astrolabes, indeed the earliest dated surviving specimen is found on the back of the astrolabe made by the celebrated Ḥāmid ibn ʿAlī al-Wāsiṭī in the year 348 H [= 959/60] (#100) and stolen some decades ago from the Museo Nazionale in Palermo—see **Figs. XIIa-10a** or **XIIIc-8.1b**.[1]

MS Cairo ṬM 155,3 (**1.3.2** and **9.5** and **Text 8**) calls this the best known of the *qilʿī*, that is, "sail-shaped" quadrants. Both al-Marrākushī and Najm al-Dīn (Ch. 57) describe it—see **Figs. 9.1a-b**—but do not use this name.[2] On the Palermo instrument, as in the first Cairo treatise and in later quadrants of this kind, including the *quadrans novus* of Profatius (**10.3**), the markings are partly obscured by a shadow-square; the combination seems to have been an established tradition. In contrast to this fine specimen are the miserable diagrams of two such quadrants (one actually movable, to what purpose it is not clear) in the treatise of pseudo-Enrique de Villena: see **Fig. 9.1c**.[3]

The construction of the hour-curves is as follows**—**see **Fig. 9.1d**. For the i^{th} hour the curve is an arc of a circle centre Y on the axis OB (produced if necessary) passing through the centre

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[1] See Mortillaro, "Astrolabio arabo"; Caldo, "Astrolabi di Palermo"; and now **XIIIc-8.1**. On the maker see Mayer, *Islamic Astrolabists*, p. 45, and Sezgin, *GAS*, VI, p. 207. The instrument illustrated in *Linton Catalogue*, p. 83, no. 160, also bears an horary quadrant and may be earlier.

[2] See Sédillot-*fils*, *Mémoire*, pp. 64-65, and fig. 2, and Charette, *Mamluk Instrumentation*, pp. 211-215.

[3] Cátedra & Samsó, *Astrología de Enrique de Villena*, pl. 15 on p. 169.

Fig. 9.1a: The universal horary quadrant illustrated by al-Marrākushī indicates that there should also scales of $\delta(\lambda')$ and $z(h)$ associated with the scale on the outer rim (running from 0° to 90° for λ' or h). The associated table displays the radii of the circular arcs corresponding to the seasonal hours. [From al-Marrākushī, *A-Z of Astronomical Timekeeping*, I, p. 363.]

Fig. 9.1c: A curious device in the treatise of Pseudo-Enrique de Villena. The combination of a poorly-drawn universal horary quadrant and a shadow square in the lower right at least makes some sense, if only historically. The "Catherine wheel"-type markings on the rotatable quadrant on the left make no sense at all. [From Cátedra & Samsó, *Astrología de Enrique de Villena*, pl. 15 on p. 169.]

Fig. 9.1b: Najm al-Dīn's illustration of the universal horary quadrant. [From MS Dublin CB 102,2, fol. 75r, courtesy of the Chester Beatty Library.]
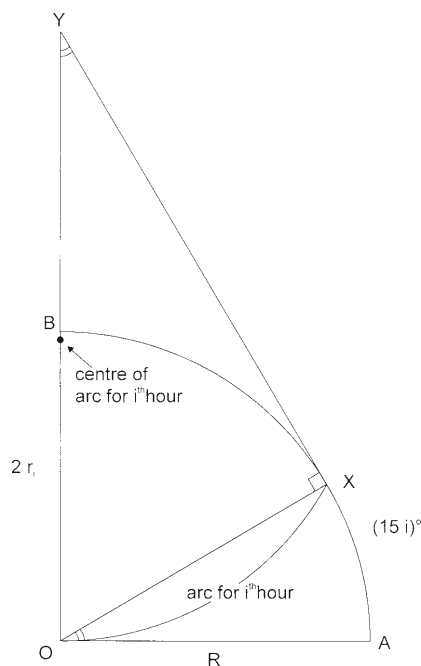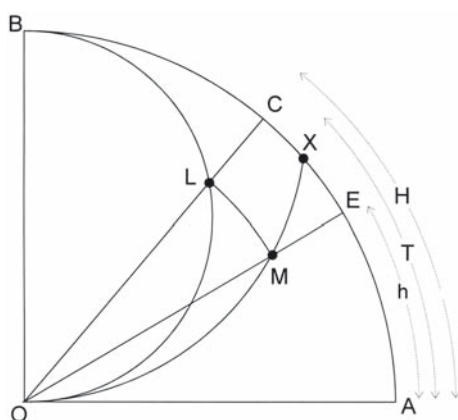
Fig. 9.1d

Fig. 9.1e

O and the point X on the altitude scale corresponding to argument (15i)°. It is not difficult to show that the radius of this arc is:

$$r_i = R / [\ 2\ \mathrm{Sin}_R\ (15i)^\circ\ /\ R\ ]\ .$$

Both al-Marrākushī and Najm al-Dīn give the radii for i = 1 to 6. The former lists them (see **Fig. 9.1a**) as:

115;53 60;0 42;26 34;38 31;3 30;0

and but for the first (in error by -2′) these are exact. Najm al-Dīn had a lapse when figuring out the radii, and his instructions are somewhat cryptic (Ch. 57).[4] His values are:

120;0 60;0 42;25 37;4 31;4 30;0,

the first one derived from the approximation Sin 15° ≈ 0;15 and the fourth one somehow derived from 18° by mistake (note that 2 Sin 18° = 37;4,55). Several authors, including the writer of the Cairo Ṭalʿat text and Najm al-Dīn, suggest using trial and error as one method of finding the centres of the arcs.[5]

Fig. 9.1e displays the use of this quadrant. Mark AC = H with the thread and set the marker at L on the intersection with the hour-curve for the 6th hour. Move the thread to OE such that AE = h and the marker to M. Then the position of M relative to the hour-curves measures T. In other words, if M lies on the hour-curve OMX, then AX = T. To justify this procedure it is sufficient to demonstrate that the circular arc OMX has its centre on OB (produced if necessary), which is trivial. Like Lorch, I am unable to think of an obvious way in which a 9th-century astronomer might have realized that the hour-curves could be represented as arcs of circles.

This quadrant was the most popular single variety in both the medieval Near East and Europe, yet it is seldom properly described in the modern literature.[6] It was common feature on Islamic

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[4] Charette, *Mamluk Instrumentation*, pp. 211-215.
[5] See Lorch, "Universal Horary Quadrant", pp. 116-117.
[6] The function and limitations of the simple horary quadrant are properly noted in van Cittert, *Utrecht Astrolabes*, pp. 45-46.

astrolabes up to the 19th century, and on European astrolabes as long as they were being produced, that is, until about the 17th century.

Around 1980, John North examined the backs of 132 astrolabes in the Museum of the History of Science in Oxford and found that 25 out of 57 European instruments and 16 out of 75 "Oriental" ones (presumably Islamic and Indian) bore such markings, with 15 out of 25 and 2 out of 16 having a double set in both upper quadrants.[7] North characterized the popularity of these markings as "an empty ritual", noting that only 4 out of 41 had associated cursors,
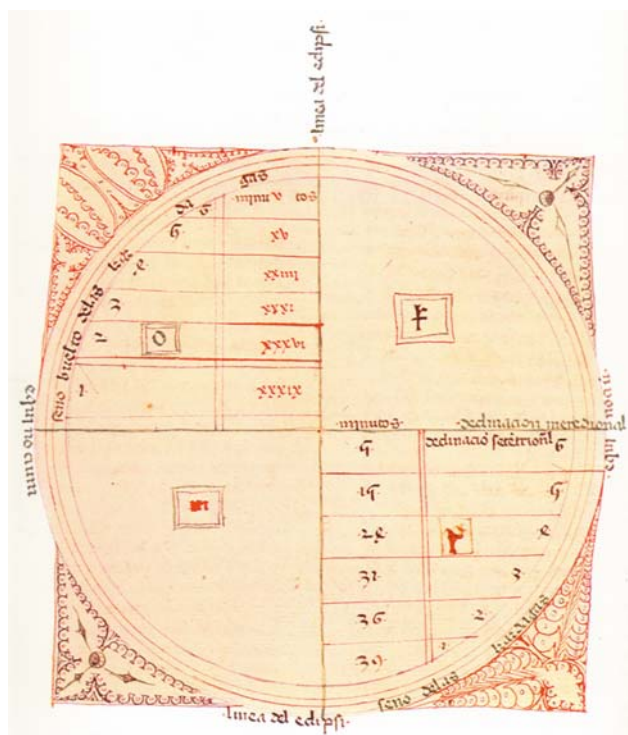
Fig. 9.2a: Not only do these two sets of parallel lines represent one of the earliest forms of horary quadrants as described in the Baghdad treatise, they also display the values of the first differences of the Sine function to base 150 (lower right) in a way that takes us right back to the beginnings of Indian trigonometry: see **9.3**. In the upper right, an attempt has been made to represent Cosines in the same way. The sets of parallels are inevitably carelessly drawn so they appear equi-spaced. [From Cátedra & Samsó, *Astrologia de Enrique de Villena*, p. 168, fig. 14.]

Fig. 9.2b: An 11th-century illustration of a *quadrans vetus* with a set of about 60 "parallels" replacing the parallels for each 15°, that is, for each seasonal hour, on one variety of the original instrument as described in the Baghdad treatise. [From MS Vatican Reginensis 1661, fol. 86v, reproduced from Millás, "Cuadrante con cursor", fig. 3.]

The descriptions in Michel, *Traité de l'astrolabe*, p. 90; Poulle, "Instruments astronomiques", pp. 9-13 of the 1983 Paris edn., and *idem*, *Sources astronomiques*, pp. 36-38; and *Washington NMAH Catalogue*, p. 32; and all of the other sources listed in nn. 10:3 and 7, in which no reference is made to the fact that the operations with this instrument are approximate, are inadequate.

[7] North, "Hour-Line Ritual".

alidades or axial scales to enable the user to "find unaided the unequal hour". He also observed that "at best, the lines can give the unequal hour with an accuracy only about half as great as that given by the convential astrolabe itself", although in fact the accuracy depends on the season and on the latitude (and, admittedly, for Europe it is quite inadequate for astronomical purposes).

Now any of the quadrants, used in conjuction with an alidade, yields $T^{sdh}(h,H)$ approximately for any latitude. If one is interested in a more accurate result for a specific latitude in equatorial degrees, one must, as North points out, use the other side of the instrument. The quadrants might well be deemed superfluous on astrolabes fitted with a set of plates, but they did provide a universal aspect to an instrument whose use was otherwise restricted to those latitudes served by its plates.[8] For the same reason they often feature on later Islamic astrolabic quadrants and European horary quadrants for specific latitudes (**10.4-5**).

9.2 The horary quadrant with parallels

In MS Cairo DM 969,4 (**9.1**) the author states that the hour-curves are drawn as straight lines in some quadrants. This must mean that they are drawn parallel to the base of the quadrant through the points (15i)° on the altitude scale. No Islamic treatise on such an horary quadrant comes to mind, and no examples of such quadrants are known to us. However, an illustration of precisely such an instrument is found in the treatise of pseudo-Enrique de Villena—see **Fig. 9.2a**.[9]

To use such a quadrant, set the marker at Sin H and move the thread so that the marker is on the parallel for h. The position of the end of the thread relative to the hour-lines measures T.

José Millás Vallicrosa drew attention to the illustration in MS Vatican Reginensis 1661, fol. 86v,copied in the 11th century, of a trigonometric quadrant fitted with a cursor reproduced in **Fig. 9.2c**.[10] Here there are no hour lines, the markings being simply about 60 "parallels", but the instrument is clearly related to those described here. Since it bears no hour lines it may be viewed as a bastard variety of horary quadrant; since it bears a cursor it may be considered an anomaly amongst trigonometric quadrants. Millás Vallicrosa labelled this instrument *quadrans vetustissimus*.

9.3 A curious table by al-Khwārizmī

In the Berlin manuscript of al-Khwārizmī's treatise on the trigonometric quadrant (**1.3.2**) is followed by two tables without associated text, one on fol. 94v of the function h(T,H) with entries to one digit (**3.1**), and the other on fols. 95r-v of a somewhat mysterious function f(T,H) with values in minutes and seconds—see **Fig. 9.3a**.[11] In both the argument H runs from 25°

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[8] This falls completely within the tradition exemplified by the material cited in **VIa** and **VIb**.
[9] Cátedra & Samsó, *Astrología de Enrique de Villena*, p. 168, fig. 14.
[10] Millás Vallicrosa, "Cuadrante con cursor", pl. IX (between pp. 80 and 81).
[11] King, "al-Khwārizmī", p. 11.

Fig. 9.3a: The curious table of *jayb al-sāʿāt.* [From MS Berlin Ahlwardt 5793, fols. 95r-95v, courtesy of the Deutsche Staatsbibliothek (Preußischer Kulturbesitz).]

to 90°. The second function is labelled *jayb al-sāʿāt li-'rtifāʿ niṣf al-nahār*, literally, "the sines of the hours for the meridian altitudes". The entries are labelled "minutes" and "seconds". By inspection,

$$f(T,H) \ = \ {}^{1}/_{60}\ f_i \bullet \mathrm{Sin}_R\ H \ / \ R\ ,$$

where the f_i are:

$$39 \quad 36 \quad 31 \quad 24 \quad 15 \quad 5\ ,$$

these being, in fact, rounded values of:

$$\mathrm{Sin}_{150}\ 15(i+1)° \ - \ \mathrm{Sin}_{150}\ 15i°\ .$$

Exactly these six values are tabulated in the *tabule kardagarum* that occurs in some copies of the *Toledan Tables*.[12] Furthermore, in the illustration of the universal horary quadrant type **b** in the treatise of pseudo-Enrique de Villena—see **Fig. 9.2a**—these values are actually marked on the axis of the quadrant.[13]

[12] Curtze, "Urkunden zur Geschichte der Trigonometrie", p. 339, and Millás, *Azarquiel*, p. 44 (also p. 418). See also n. 2:6.

[13] See the commentary in Cátedra & Samsó, *Astrología de Enrique de Villena*, pp. 50-51.

At first encounter with this table, it was not clear precisely why al-Khwārizmī tabulated f(T,H). Notice that the entries are given to two sexagesimal digits whereas the f_i are given only to one. Notice also that by virtue of our formula:

$$f_i(H) = \text{Sin } h_{i+1}(H) - \text{Sin } h_i(H),$$

which indicates that the name *jayb al-sāʿāt* means fully "the first differences of the Sines of the altitudes at the seasonal hours for each degree of meridian altitude".

The nature and purpose of this table has been explained by Jan Hogendijk; however, even he is not sure why al-Khwārizmī would have tabulated such a function.[14] Hogendijk has shown that the function f(T,H) displays the first differences of the function Sin_{150} h(T,H), according to the standard approximate formula, thus:

$$f(T.H) = \text{Sin}_{150}h(T,H) - \text{Sin}_{150}h(T\text{-}1,H) = \text{Sin}_{150}H \bullet [\text{Sin}_{150}(15T) - \text{Sin}_{150}(15T\text{-}15°)] / 150 ,$$
$$f(1,H) = \text{Sin}_{150}h(1,H) = \text{Sin}_{150}H \bullet \text{Sin}_{150}(15°) / 150 .$$

To find Sin h(T,H) for T = m;n (1 < m < 5, 0 < n < 60), one simply computes with the values in the table, as follows:

$$\text{Sin } h(T,H) = f(1,H) + f(2,H) + ... + f(m\text{-}1,H) + ({}^{1}/_{60}\ n) \bullet f(m,H) .$$

Now values of h(T,H) are available in the first table discussed above, this table of f(T,H) for finding Sin h(T,H) is superfluous. But, as Hogendijk has stressed, it provides useful insights into the earliest Muslim encounters with trigonometry. Hogendijk was able use the table to reconstruct the original Sine table that al-Khwārizmī used to generate it, which was not available to us from other sources.

A 10th-century astrolabe bears a remarkable and unique feature relating to our study. The instrument was made by Aḥmad and Maḥmūd, sons of Ibrāhīm, in Isfahan in the year 374 H [= 984/85], and it is now housed in the Museum of the History of Science at Oxford.[15] There is a scale is to the right of the vertical radius bisecting the upper semi-circle on the back of the instrument, contiguous with the trigonometric quadrant, and it is labelled *sāʿāt zamāniyya li-kull ʿarḍ,* "seasonal hours for all latitudes"—see **Fig. XIIIc-10c**. Essentially the segments marked on this scale, which are precisely those cut off by the family of parallels for each 5° of argument on the scale of the trigonometric quadrant, display values:

$$\text{Sin}_R\ 5(i+1)° - \text{Sin}_R\ 5i° \quad \text{for} \quad i = 0, 2, ... , 17$$

theoretically for any R, although the alidade bears a scale subdivided into units of 5 for R = 60, so that probably this base was intended. These arguments, if multiplied by Sin_R H / R, would indicate the increase in the sines of the altitudes at each one-third seasonal hour for that particular H. I confess that the application of this scale is still not completely clear to us, and wonder whether the caption might refer to the entire trigonometric quadrant, which after all serves precisely the purpose indicated in the caption—see **8.1**. On the other hand, the other markings in the upper right and below the horizontal diameter are later additions.

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[14] See now Hogendijk, "al-Khwārizmī's Sine of the Hours".

[15] On this instrument (#3) see already Gunther, *Astrolabes*, I, pp. 114-116 (no. 3) and pls. XXII-XXIII, also n. 15:2 to **XIIa**, and now **XIIIc-10**.
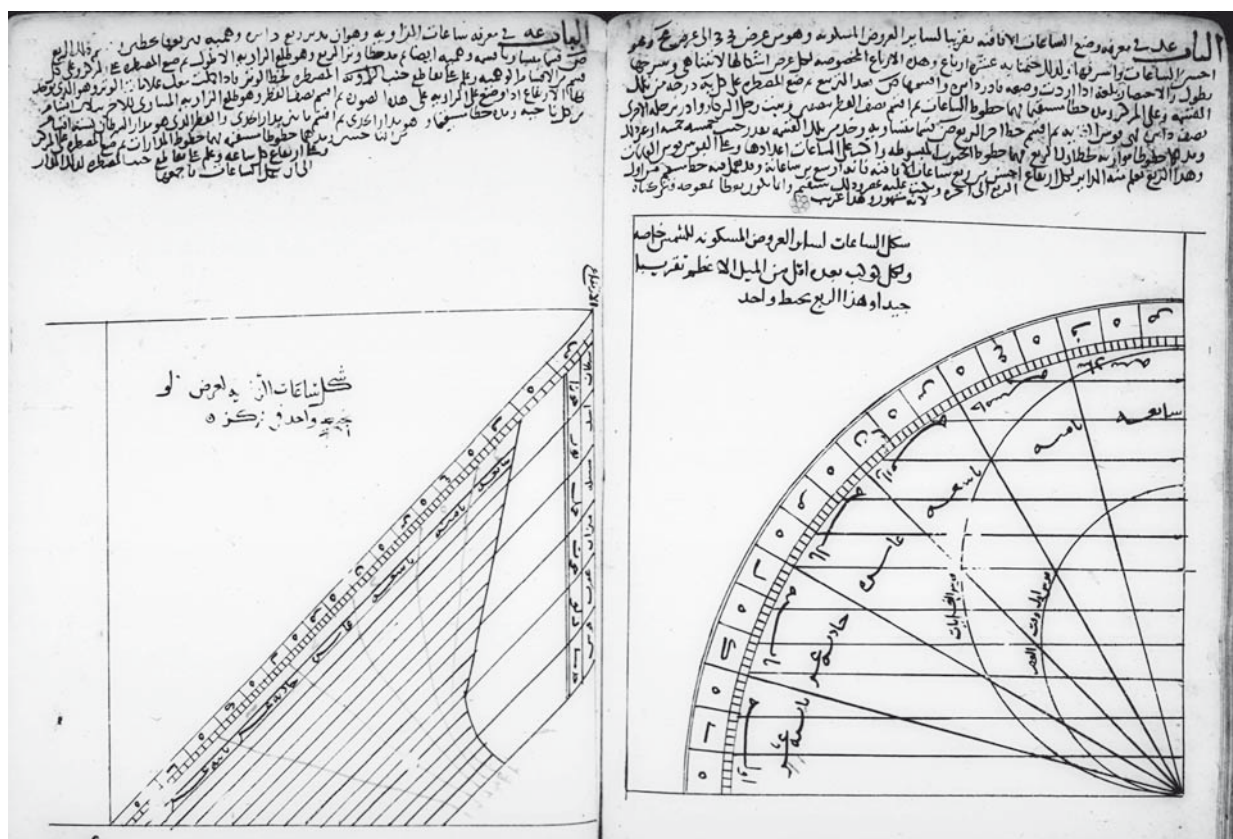
Fig. 9.4a: Najm al-Dīn al-Miṣrī labels the markings on the quadrant on the right "the hours for all inhabited latitudes, especially for the sun". He adds that it can also be used for stars with declination less than the obliquity, but then the results are awkward "stellar hours". He also notes that it is approximate, but excellent. The illustration on the left shows a special dial for latitude 36°, one of dozens of remarkable devices now described in Charette, *Mamluk Instrumentation*. [From MS Dublin CB 102, fols. 92v-93r, courtesy of the Chester Beatty Library.]
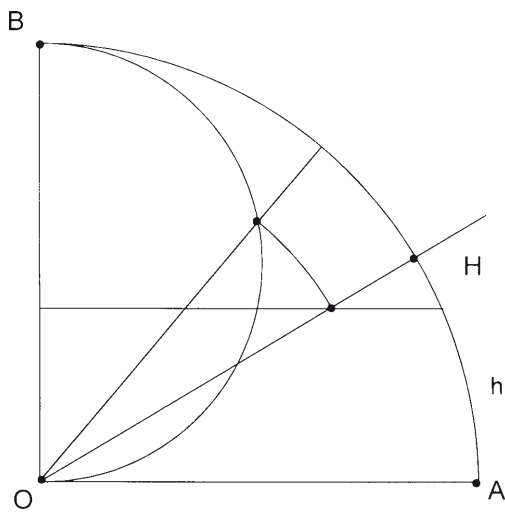
Fig. 9.4b
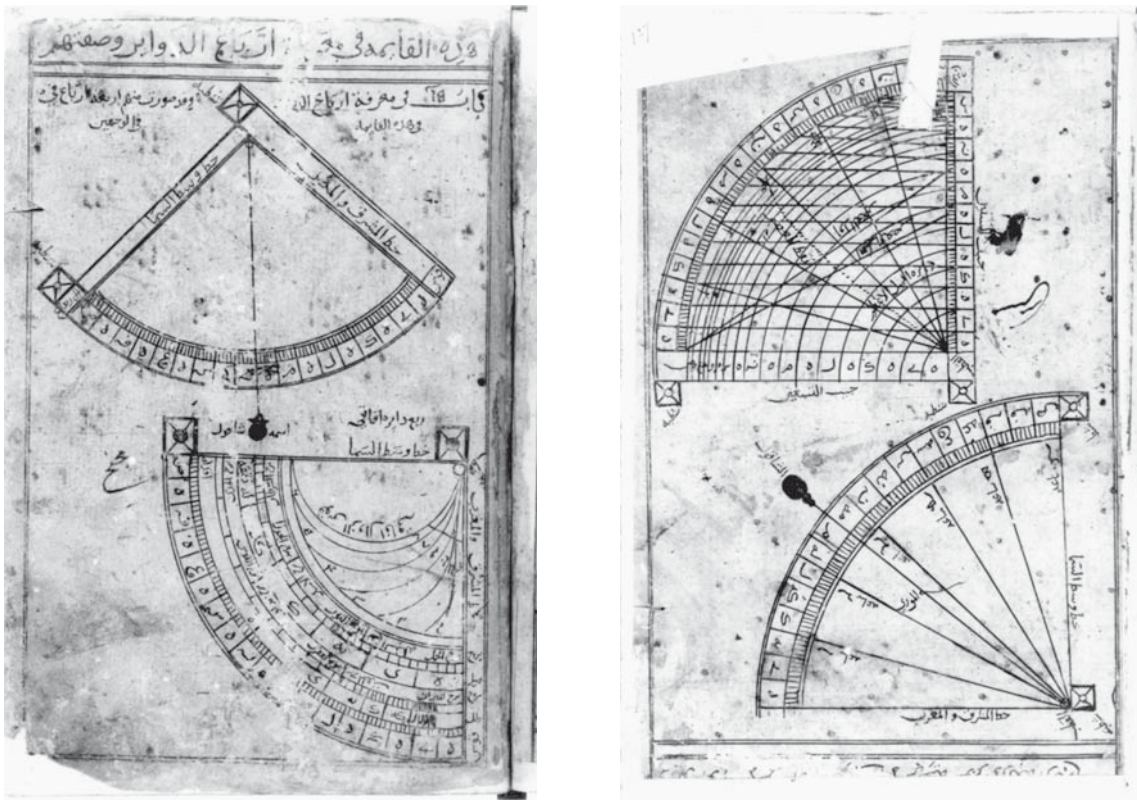
Fig. 9.4c: Illustrations of four quadrants in a 14th-century Egyptian treatise on timekeeping for muezzins. These show: (1) a simple altiutude quadrant without markings beyond an altitude scale; (2) a universal horary quadrant with scales for the solar declination and shadows to base 7; (3) an horary quadrant of type 3, with equally-spaced radial markings for the hours, labelled as such; and (4) a sine quadrant with parallels for each 5° and corresponding quarter-circles, as well as a small quarter-circle (with radius 24 units of the radius taken as 60) for finding the solar declination and two almost-rectilinear curves for finding the altitude of the sun at the beginning and end of the *ʿaṣr* prayer. See also **Figs. II-6.1** and **V-5.1a-b**. [From MS Oxford Bodley 133,2, fols. 127r-v, courtesy of the Bodleian Library.]

9.4 The horary quadrant with radial markings (type c)

In MS Cairo DM 969,4 (**9.1**) the anonymous Abbasid author also mentions that the hour-curves can be drawn as radii of the quadrant. Precisely such an instrument is also described by Najm al-Dīn (Ch. 74), now fitted with a special semi-circular curve for feeding in H and another for finding h_a from H—see **Fig. 9.4a**. This combination represents a very simple means for finding T(h,H) —see **Fig. 9.4b**. Set the thread to H on the altitude scale and move the marker to where the thread cuts the meridian altitude semi-circle. Then move the thread so that the bead lies on the parallel through h. The position of the bead relative to the hour-lines indicates T.
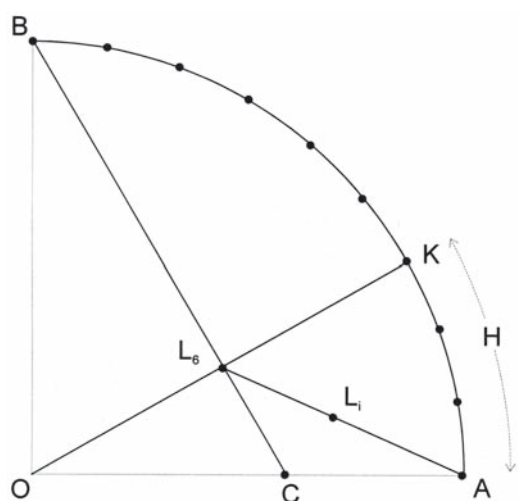
Fig. 9.5a
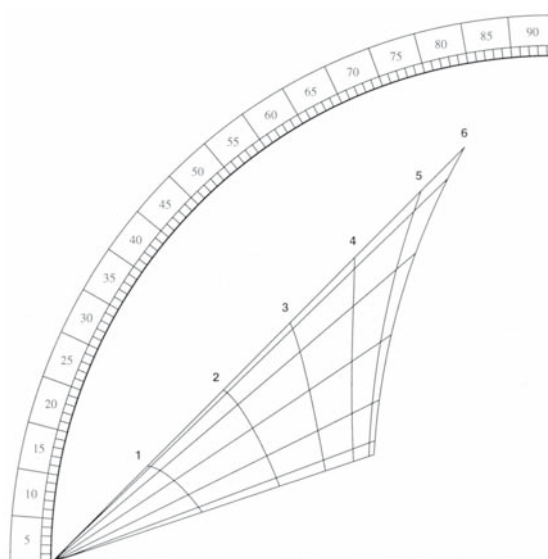
Fig. 9.5b: An example of such a quadrant for a specific latitude described by Najm al-Dīn al-Miṣrī. This variety he calls the "horary (quadrant with the markings in the form of a) harp", in Arabic *sāʿāt al-junk*. [From Charette, *Mamluk Instrumentation*, Fig. 3.10 on p.131, courtesy of the author.]

No such quadrants are known to us, but an illustration from a 14th-century Egyptian source, actually a handbook for muezzins (**II-6.1** and **V-5**), preserved in the unique copy MS Oxford Bodley 133,2, fols. 94v-130r, completed in 734 H [= 1333/34], is shown in **Fig. 9.4c**. The radial markings are indeed labelled "hours". A similar instrument is illustrated in G. Reich, *Margarita philosophica* (1504); Ptolemy is depicted using it to make a sighting on the moon.[16]

9.5 The horary quadrant with sail-shaped markings (type d)

The anonymous Andalusī treatise preserved in MS Cairo ṬM 155,3 (**1.3.2**) describes twelve different kinds of horary quadrants—see **Text 8**. The first is the universal quadrant with circular arcs (type **a** above). Another is likewise universal, but is attested only in this treatise; it is a modification of a variety of quadrant for a specific latitude also mentioned in the treatise. In neither case is there any mention of a cursor.

I refer to **Fig. 9.5a**. On the axis OA of the quadrant OAB choose an arbitrary point C, preferably about its midpoint. Draw BC as the "line of meridian altitudes". For each K on the

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[16] Reproduced in Poulle, *Sources astronomiques*, p. 19, where it is stated:
"le dessin du quadrant est si sommaire qu'il est à peu près indéfinissable; les six rayons convergents au sommet [there should only be five !] se veulent sans doute des lignes horaires; de plus, l'instrument est mal tenu."
Actually all that is missing is a semi-circle for the meridian altitudes. Ptolemy is shown holding the quadrant with sights aligned with the moon.

arc AB such that AK = H = (10n)° for n = 1, 2, ... , 9, determine the point of intersection of OK with BC, namely L_6, and draw AL_6 to serve as the *madār* of that particular H. Then mark L_i for i = 1 to 5 on AL_6 by reading off $h_i(H)$ from a table. Joining corresponding points L_i for i = 1 to 6 for each value of H produces the hour-curves. No quadrants of this variety are known to have survived. al-Marrākushī and Najm al-Dīn mention quadrants of this kind for specific latitudes (see **Fig. 9.5b**).[17]

9.6 Some remarks on the cursor

I stress that the universal horary quadrant functions perfectly well for all latitudes (within the limits of the underlying approximation) with a simple circular scale. It is a common misconception in the modern literature that the instrument *needs* a cursor to make it usable in any particular latitude. Providing a cursor serves only to obviate the need to know H in advance—see further **10.1**.

Note that Ibn al-Zarqālluh (**8.2**) must have been familiar with this tradition since he put a cursor on the quadrant that bears his name. The quadrant labelled by Millás Vallicrosa as *quadrans vetustissimus* (**9.2**) demonstrates that the use of cursors was so widespread that they were even applied to trigonometric quadrants on which they were actually superfluous.

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[17] Charette, *Mamluk Instrumentation*, pp. 129-131.

CHAPTER 10

THE *QUADRANTES VETUS* AND *NOVUS*

Profatius labelled his quadrant *robaʿ Yisrael* in his Hebrew guide to its use, and it was known in Latin as *quadrans novus*. The simpler universal horary quadrant with cursor later became known as *quadrans vetus* in order to distinguish it from Profatius' instrument.[1]

10.1 The *quadrans vetus* in the Islamic Near East

The Abbasid treatise in MS Cairo DM 969,4 (**1.3.2** and now **XIIa-2** and **App. A**) mentions that each of the quadrants mentioned in **Ch. 9** might have a movable cursor. This would be about 47° (≈ 2ε) long and would need to be centred on the meridian altitude at the equinoxes ($\bar{\phi}$) for the latitude in question. It could bear a scale for the date, or the solar longitude λ, or the solar declination δ. (Actually a cursor one-half this length will suffice, but then the calendrical scale becomes more complicated.) In the case of an instrument fitted with such a device, one does not have to worry about H: one simply sets the thread to the appropriate date, solar longitude λ or declination δ on the cursor, fixes the bead at the intersection with the curve for the 6th hour, and then makes the observation to find T. The principle is identical, so that the quadrant is no less approximate.

Precisely the quadrant of **9.1** fitted with a cursor is the so-called *quadrans vetus* of the European sources—see **10.2**. But the author of the Cairo treatise makes no claim to have invented the six instruments he mentions, indeed, it is clear that they enjoyed wide circulation at his time. The encyclopaedist Abū ʿAbdallāh al-Khwārizmī,[2] not to be confused with the astronomer Abū Jaʿfar al-Khwārizmī, wrote about the year 975 that the quadrant was for "measuring altitudes and finding the hours of day", which—if further evidence was necessary—proves that some sort of horary quadrant, not necessarily the universal variety, was well known in the Eastern lands of Islam in the 10th century. However, no universal horary quadrants with cursor have survived from the Islamic world.

10.2 The *quadrans vetus* in Europe

The story of the *quadrans vetus* in Europe—the various treatises on it by Hermannus Contractus, Robertus Anglicus, Johannes de Sacrobosco, and the few surviving examples—has been told so often that there is no need to repeat it here.[3] Suffice it to say that we have

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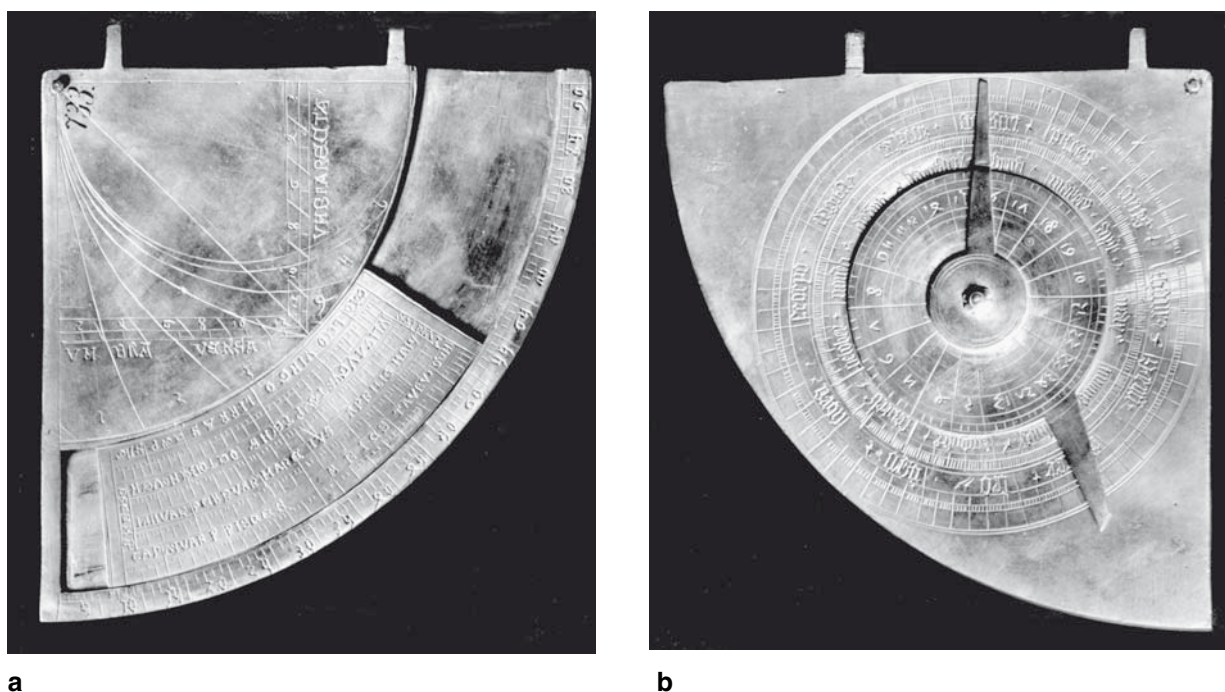
[1] Poulle, *Sources astronomiques*, p. 40.
[2] Abū ʿAbdallāh al-Khwārizmī, *Mafātīḥ al-ʿulūm,* Beirut, 1984 edn., p. 253.
[3] See Tannery, "*Quadrans vetus*", on the treatise of Robertus Anglicus; Delambre, *HAMA*, pp. 243-247,

a **b**

Figs. 10.2a-b: A *quadrans vetus* of uncertain date and provenance (#5505). The horary markings, with superposed shadow square, and (optional) solar declination cursor are as described in the Baghdad treatise. The luni-solar scales on the back are typical of the European tradition, and are not mentioned in the Arabic text. This particular example has been considered a fake by the museum authorities, but there is no reason to doubt its authenticity, even though it is silver coated. More problematic is the provenance: the orthography LIRRA for LIBRA on the cursor suggests Catalonia, but the engraving is more typical of Northern France or Germany. [Photos from the Zinner Archiv, Institut für Geschichte der Naturwissenschaften, Frankfurt; object in the Kunsthistorisches Museum, Vienna.]

established that the very same instrument was invented in Baghdad in the 9th century. The details of its transmission to Europe via Spain are not known. **Figs. 10.2a-b** display an unpublished example (#5505) preserved in Vienna. The fine European example from *ca*. 1400 preserved in Florence is illustrated in **Fig. XIIa-2c**.[4]

Bernard Goldstein has recently identified what he thought was a description of a *vetus* quadrant in a text by Mordecai Comtino (*fl*. Constantinople, 15th century) extant in MS Paris BNF heb. 1053, fols. 66r-71v.[5] But here the zodiacal signs are marked on a radius, which leads

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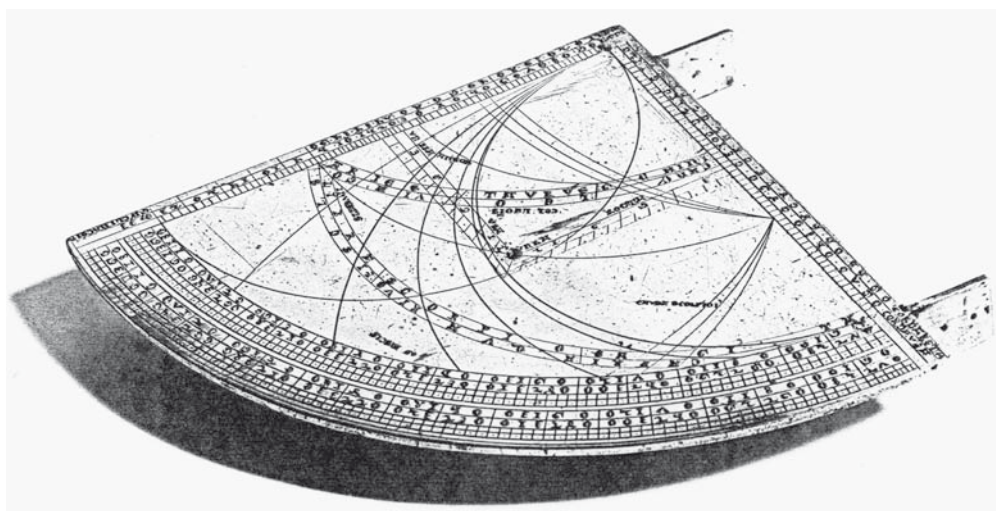
and Knorr, "Sacrobosco's *Quadrans*", on the treatise of Sacrobosco. For overviews see Gunther, *Early Science in Oxford*, II, pp. 156-163; Zinner, *Astronomische Instrumente*, pp. 156-159; North, *Richard of Wallingford*, II, pp. 184-185; Poulle, *Sources astronomiques*, pp. 40-42; A. J. Turner, *Early Scientific Instruments*, p. 25; and Knorr, "*Quadrans Vetus*". In Sarton, *IHS*, II:2, pp. 850-853 and 993-994, both quadrants are misunderstood. See also n. 9:6.

Pedersen, "The Corpus Astronomicum", pp. 75ff., and *idem*, "Medieval European Astronomy", p. 322, describes the corpus of European astronomical works—including a treatise on the *quadrans vetus*—popular in early European universities.

[4] See also Poulle, "Instruments astronomiques", 1969 edn., p. 19 (Oxford instrument), and 1983 edn., p. 10 (Florence instrument), for other examples of the *vetus* variety.

[5] Goldstein, "Astronomical Instruments in Hebrew", p. 123.

Figs. 10.3a-b: The front and back of a French qua*drans novus* dating from the 14th century (#5507). The surviving medieval examples are neither signed nor dated, which is unhelpful. Also, the latitudes are never labelled, and the underlying parameter must be derived from the associated axial scale (here a disaster) serving declinations, and, sometimes, also the complement of the latitude. Here the horizons (meeting the equinoctial circle at the right-hand axis) are for three latitudes of about 41°, 45° and 48°, which establishes the provenance, at least roughly. The two arcs of the ecliptic meet equinoctial circle at the left-hand axis. The horary universal horary markings provide a quick means of finding time from solar altitude approximately, but not accurately in European latitudes. The back of this instrument bears calendrical scales, which is unfortunate because the astrolabic markings on the front serve only the most basic horizon-related problems, and for anything more serious, such as reckoning time of day from solar altitude properly, one needs a trigonometric grid. [Photocopy from the Museum of the History of Science, Oxford; object in the National Museum of American History, Washington, D.C.]

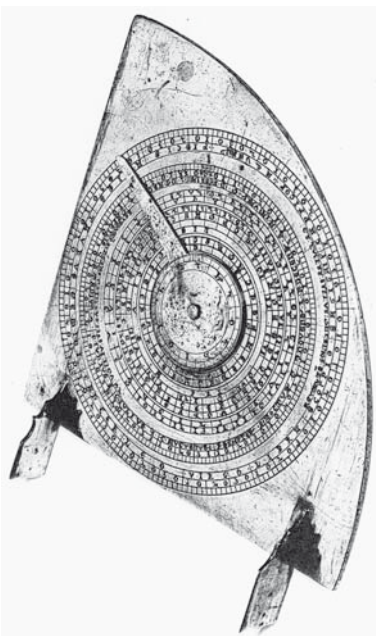



Fig. 10.3b

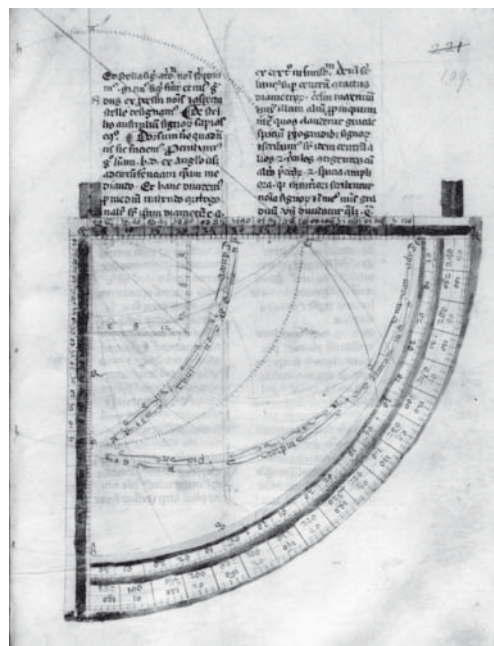



Fig. 10.3c: An illustration of a *quadrans novus* in a medieval manuscript. Horizons are drawn for two latitudes, *ca*. 40° and 50°. [From MS Oxford Tanner 192, fol. 109r, courtesy of the Bodleian Library.]

us to suspect that the instrument described was in fact a quadrant for a specific latitude.

Ernst Zinner stated that *quadrantes vetustissimi* in wood were still being made in Sweden in the 18th century.[6] One hates to think of anyone sober actually trying to use the device anywhere near the Arctic Circle, for there the seasonal hours cease to be defined, but one should not underestimate the Swedes.

10.3 The *quadrans novus*

The story of the *quadrans novus*—its introduction by Profatius in his two treatises of 1288 and 1301, the various treatises on it compiled over the centuries, and the few surviving examples (see **Fig. XIIa-8a**)[7]—likewise does not bear repeating here. Suffice it to remark that no Islamic precedents for the distinctive *combination* of the markings and cursor of the *vetus* and the stereographic projections of the ecliptic and various horizons—have been found. Furthermore, and contrary to various claims in the modern literature, the European instrument did not—as far as I am aware—reach the Islamic world. The *vetus* and *novus* are horary quadrants (they display hour-curves) and not astrolabic quadrants (they display neither altitude circles nor azimuth circles). Thus they do not function like an astrolabe. The combination referred to above is not a happy one: the solar positions found from the ecliptic projection are inappropriate for the universal hour-curves, not least because the original function of the curve for the sixth hour is now lost. One could be forgiven for thinking that, for example, the solar midday altitude at the sixth hour at the summer solstice was 90°. The ecliptic can be used in conjuction with the horizons for a limited number of operations involving sunrise and sunset, such as finding the length of daylight. It is possible to adjust the universal horary quadrant sensibly to a specific latitude and, as I shall show (**11.2** and **11.3**), this was done by some Muslim astronomers. It was also done by some European astronomers (**11.2** and **11.4**), but Profatius was not one of them.

The "intermediate instrument" of al-Ḥadib (*fl*. Sicily, late 14th century) described *ibid*., pp. 121-123, is the same as the special astrolabic plate of Ibn al-Shāṭir (*fl*. Damascus, *ca*. 1350—see article in *DSB* and Mayer, *Islamic Astrolabists*, pp. 40-41 (no. I), of which an example survives in the Museum of Islamic Art in Cairo (see n. 12 to **XIIa-8**). On this, projections of the ecliptic and stars are superposed on those for a local horizon. A late Egyptian "intermediate instrument" is preserved in the National Maritime Museum in Greenwich: see *Greenwich Astrolabe Catalogue*, in press.

[6] Zinner, "Wissenschaftliche Instrumente", p. 69.

[7] On the *quadrans novus* see especially Anthiaume & Sottas, "*Quadrans novus*"; Poulle, "*Quadrans novus*"; and also Zinner, *Astronomische Instrumente*, pp. 156-159; *Oxford MHS Billmeir Supplement Catalogue*, pp. 44-45; North, *Richard of Wallingford*, II, pp. 184-185; Poulle, *Sources astronomiques*, pp. 36-38; Maddison & Turner, *London SM 1976 Catalogue*, pp. 150-151; and *Rockford TM Catalogue*, I, pp. 202-206, and 3, p. 16.

The otherwise masterful account of one particular instrument of this kind and its applications in Anthiaume & Sottas, *op. cit*., overlooks completely the fact that the main function of the more important side of the instrument is approximate. (Profatius, of course, was well aware of this: the accurate formula could be applied on the other side of the instrument, which was generally, though not always, a sine quadrant.)

In *Rockford TM Catalogue*, I, p. 214, it is claimed that what is called a Profatius quadrant—but is actually an astrolabic quadrant—does not display the entire ecliptic. The confusion in this case seems to arise from an unfortunate diagram of an incorrectly-drawn astrolabic quadrant labelled "Prophatius quadrant" (*ibid*., p. 203, fig. 167, and A. J. Turner, *Early Scientific Instruments*, p. 15, fig. 6).

CHAPTER 11

THE UNIVERSAL HORARY QUADRANT IN LATER ASTRONOMY

11.1 Some remarks on astrolabic quadrants for a specific latitude

The astrolabic quadrant, a more mathematically-successful quadrant than the *quadrans novus*, without the curves for the seasonal hours, was devised by an unknown Muslim astronomer in Cairo (**X-6.3**), more than a century before the time of Profatius. See **Fig. X-6.4.1a-b** for a 14th-century example. This instrument was not known in Europe. Numerous late Islamic examples of this instrument bear universal horary markings in addition to the astrolabic markings for a fixed latitude—see, for example, **Fig. X-6.4.2**.

11.2 Some remarks on horary quadrants for specific latitudes

Horary quadrants serving a single latitude, first devised in the 9th century, require an axial (or some other) scale for feeding in the solar longitude or meridian altitude as one argument. In **4.1** I have described a table of $h_i(\lambda)$ for marking such a quadrant, which happens to be based on our formula. Four Islamic examples from the 10th to the 13th century are known—see **Figs. XIIIa-8.1b**, **13** and **A2** for three of these.[1] The text preserved in MS Cairo ṬM 155,3 (**1.3.2**), which is apparently of 11th- or 12th-century Andalusī origin, describes *twelve* ($2 \times 2 \times 3$) different varieties with curved or straight hour-curves, universal or serving a particular latitude, and displaying seasonal hours, equinoctial hours, or the time since sunrise. The various kinds described by al-Marrākushī are taken from this treatise or one very much like it and it is Najm al-Dīn who suggested numerous more examples, some of which we actually find attested on later instruments (also on some European examples).[2] As noted above (**10.2**), it seems probable that the horary quadrant described by Mordecai Comtino in Constantinople in the 15th century was intended for a fixed latitude.

Only one such quadrant is known to us from the later Islamic period: it is on the back of an astrolabe made by one ʿAbdī in Istanbul in 1125 H [= 1713/14] and now preserved in the Museum of the History of Science at Oxford—see **Fig. X-6.3.1**.[3] In addition to a sexagesimal

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[1] These are surveyed in Viladrich, "Horary Quadrants".

[2] The Islamic varieties described by al-Marrākushī and Najm al-Dīn—which include all those known from the Islamic sources—are described in Charette, *Mamluk Instrumentation*, pp. 116-139.

[3] On this piece (#1222) see Mayer, *Islamic Astrolabists*, p. 32; *Oxford MHS Billmeir Supplement Catalogue*, pp. 28-29 (no. 171A), and pls. XXI and XXIIa; also King, *Studies*, B-XIV, p. 375 (where the markings are improperly described).

trigonometric quadrant and a universal horary quadrant (type **a**), it bears a quadrant of markings for the equinoctial hours for a specific latitude, actually 41° (serving Istanbul). There are ecliptic markings only for the solstices and equinoxes and the alidade is unmarked; thus the ensemble can only be used to find the solar altitude at these three times of the year.

We now turn to European horary quadrants. Already on a remarkable French geared astrolabe from *ca*. 1300 preserved in the Science Museum, London, there is a double horary quadrant for the equinoctial hours (for a latitude of roughly $49^1/_2$°)—see **Fig. X-6.3.2**.[4] The hour-curves are drawn as arcs of circles, and the radial solar scale adjusted accordingly. Not only are the markings for each ten days of each month found on the quadrant itself, but markings for the zodiacal signs are on the alidade. Likewise on the late-16th-century astrolabe of Philis de Din, there is a similar quadrant for the equinoctial hours, this time alongside a modified universal quadrant for the seasonal hours; both serve a latitude of about 50°.[5] I suspect, but cannot prove, that these quadrants for a specific latitude are direct descendants of an Andalusī tradition.

A related tradition with uniform solar scales, and hence sigmoid hour curves, is represented by the later horary quadrants for specific latitudes such as those of P. Lansberg and N. J. Vooghd. These also bear our universal quadrants, if with the extremities of the hour-curves trimmed.[6]

All of these horary quadrants are graphic representations of the solar altitude as a function of solar longitude and time of day, which distinguishes them from the analogue devices such as the astrolabe and astrolabic quadrant even though they function—like an astrolabe plate—for a specific latitude. Nevertheless, even on some Gunter-type and similar quadrants for a specific latitude from as late as *ca*. 1700, as on many European astrolabes up to about the same time, we find a universal horary quadrant tucked inside the main markings.[7]

11.3 Islamic modifications to the universal horary quadrant with circular arcs

A positive development: the axial semi-circles on trigonometric quadrants

On trigonometric quadrants from the 14th century onwards we often find a pair of axial semi-circles for setting the bead on the movable thread to the Sine or the Cosine of any arc—see **Figs. 8.1d**, also **XIVb-10b**, and, for a Renaissance European example, **Fig. 11.3a**.[8] It may be that this simple, ingenious device was originally inspired by the meridian curve on the universal horary quadrant. Further investigation is necessary to clarify this point.

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[4] Gunther, *Astrolabes*, II, p. 347 (no. 198) and pls. LXXX and LXXXI; North, "*Opus quarundam rotarum mirabilium*", pp. 369-371; also King, *Ciphers of the Monks*, pp. 398-399 and 402-403.

[5] See n. 11:19 below.

[6] See van Cittert, *Utrecht Astrolabes*, pls. XVI, XVIII; also Viladrich, "Horary Quadrants", p. 321 and pl. 5 on p. 345.

[7] For example, the instrument illustrated in Wynter & Turner, *Scientific Instruments*, p. 26, fig. 20.

[8] In G. Turner, *Elizabethan Instruments*, p. 99, the invention of this device is taken back only as far as Apian.

Fig. 11.3a: The axial semicircles on a quadrant (#5543) from Elizabethan England. [Courtesy of the Museo di Storia della Scienza, Florence.]

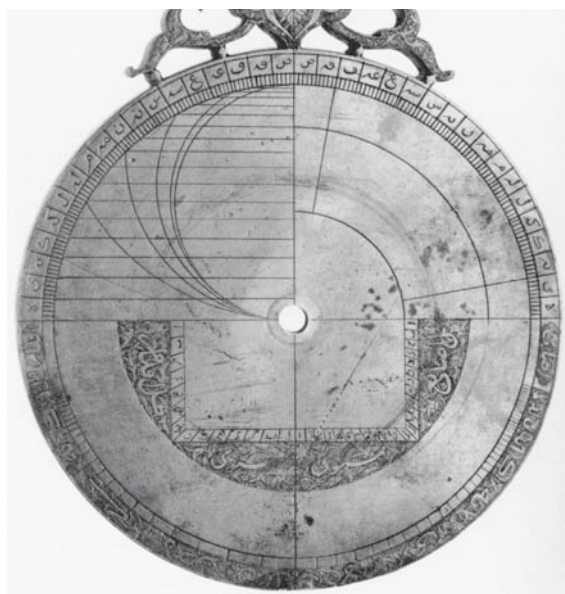



Fig. 11.3b: Universal horary markings superposed on trigonometric markings on a late Iranian astrolabe (#54). The zodiacal quadrant on the upper right has not been completed. [Courtesy of the National Museum of American History, Washington, D.C.]

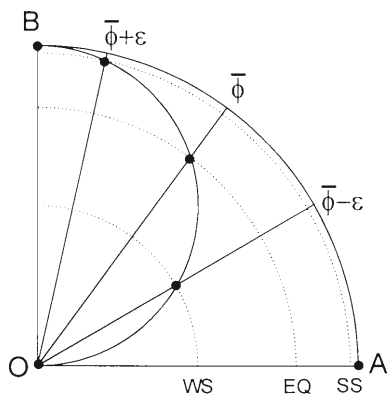
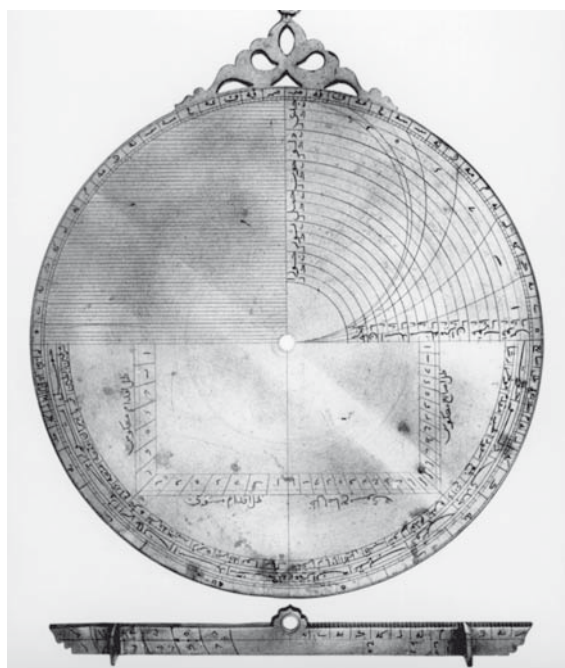



Fig. 11.3c

→

Fig. 11.3d: The universal horary quadrant on the back of an astrolabe (#2502) by Muḥammad Ṣāliḥ of Tatta in Sind, with a solar scale which implies that the sun reaches the zenith at the (summer) solstice. The latitude of Tatta, which is apparently not featured in Eastern Islamic geographical tables, is close to 25°, so that this is not silly. But the solar scales have been reversed, so the maximum altitude corresponds to the winter solstice: the combination is thus absurd. [Courtesy of the Museum of the History of Science, Oxford.]

Some less happy developments

The provision of a universal horary quadrant with a cursor (**10.1**) does not really mark a great step forward, but it was at least harmless, as opposed to various other modifications to which we now turn.

Combinations with markings of trigonometric quadrants

On late (18th - and 19th-century) Indo-Iranian astrolabes the universal horary quadrant type **a** was occasionally superposed on markings usually associated with different varieties of trigonometric quadrant—see **Fig. 11.3b**. This was not a particularly happy development, and I suspect that those who did this had no real understanding of either of the grids they drew together. I note the following examples of other markings combined with hour-curves:[9]

(1) a family of horizontal parallels for each 5° of arc;
(2) a grid of concentric quadrants for each 5 units radius and a set of parallels for each 5° of arc;
(3) a grid of horizontal and vertical parallels for each 5° of arc;
(4) a family of 60 horizontal parallels for each unit of argument on the vertical axis;
(5) a family of 90 parallels for each 1° and radial lines for each 5°;
(6) a sexagesimal sine grid, with 60 horizontal and 60 vertical parallels for each unit of argument on both axes.

Solar longitude scales

Also unfortunate were various attempts by late Muslim astrolabists to provide an axial ecliptic scale (such as is necessary on an horary quadrant for a specific latitude). In theory, adding a solar longitude scale in the form of, say, three concentric quadrants to serve the winter solstice, the equinoxes, and the summer solstice in the right places links the quadrant to a specific latitude.[10] The position of the three arcs is easily determined when one knows the corresponding midday altitudes, $\bar{\phi} - \varepsilon$, $\bar{\phi}$, and $\bar{\phi} + \varepsilon$—see **Fig. 11.3c**.

Such ecliptic scales are found on some Indo-Iranian astrolabes from the 17th century—see **Fig. 11.3d**.[11] But the rim of the quadrant in each case serves the winter solstice, which means

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[9] (1) *Linton Catalogue*, p. 115, no. 175; *Washington NMAH Catalogue*, p. 94, no. 54 (**Fig. 11.3b**);
(2) *Rockford TM Catalogue*, I, pp. 100-103;
(3) *Washington NMAH Catalogue*, p. 99, no. 57;
(4) *Ibid*., p. 34, no. 25;
(5) *Collection de. M. R... et de divers amateurs*: *Instruments scientifiques anciens* [a catalogue of instruments offered for sale by J. Lenormand & P. Dayen, E. Libert & A. Castor, and A. Brieux in Paris in 1982], Paris, 1982, no. 81 = Mayer, *Islamic Astrolabists*, p. 25 and pl. XVII (made by Muḥammad Mahdī al-Yazdī *ca*. 1650);
(6) *Washington NMAH Catalogue*, p. 109, no. 61, fig. 70.

The early-19th-century Indian astrolabe with Sanskrit inscriptions illustrated in *Washington NMAH Catalogue*, p, 183, no. 4000, has hour-curves superimposed on 18 concentric circles, but these serve a radial solar scale—see n. 11:11.

[10] In North, "Hour-Line Ritual", p. 113, it is erroneously assumed that the universal horary quadrant *has to have* a solar longitude scale to function "properly".

[11] (1) *Oxford Billmeir Supplement Catalogue*, pl. XIX (made by Muḥammad Ṣāliḥ in 1077 H [= 1666/67], reproduced as **Fig. 11.3d**.
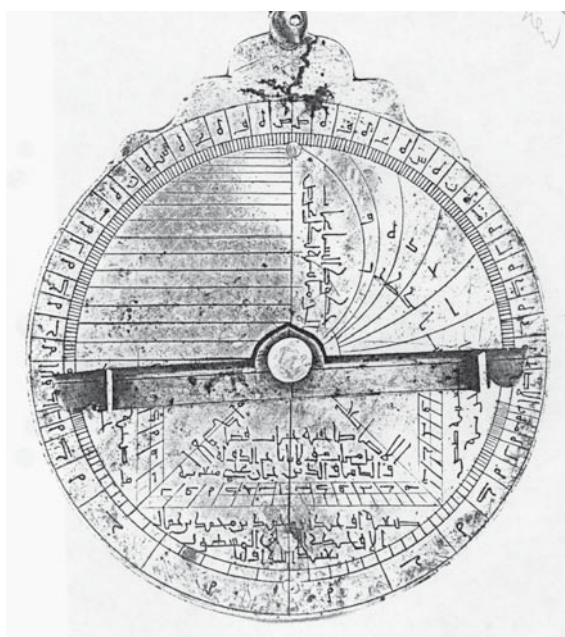
Fig. 11.3e: Incompetently-constructed markings for the seasonal hours on the back of an astrolabe (#112) made in 890 H [= 1485/86] by Awḥad ibn Muḥammad al-Awḥadī. Our Awḥad, whose name means something like "(more) unique", is indeed unique: his is the only Islamic astrolabe from before *ca*. 1600 known to me that features incompetent markings of this kind. [Courtesy of the British Museum, London.]
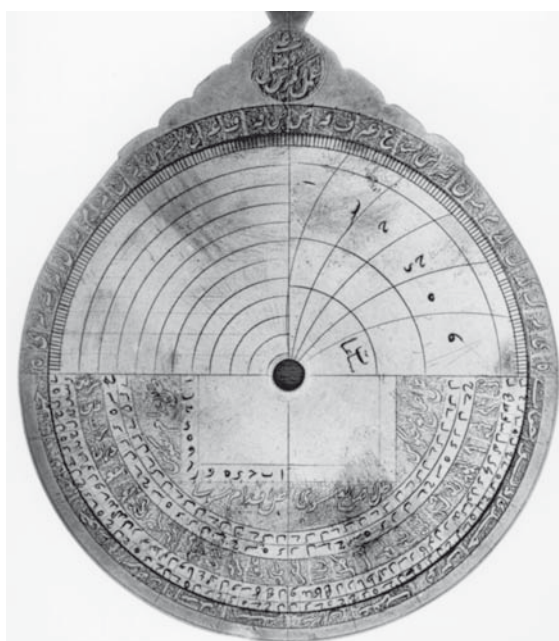
Fig. 11.3f: The "Catherine wheel"-type horary markings on this late Iranian astrolabe (#76) are so distorted as to be useless. [Courtesy of the Museum of the History of Science, Oxford.]

that the combination is absurd. Nevertheless the reason for the confusion is clear. From the 10th century onwards astrolabists occasionally included a graphical representation of the solar meridian altitude for one or a series of latitudes in a quadrant on the back of an instrument. Alternatively they might graph the solar altitude at midday and at the time of the ʿ*aṣr*.[12] The earliest quadrants had linear solar longitude scales so that the curves were generally sigmoid

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(2) Wynter & Turner, *Scientific Instruments*, p. 17, fig. 10 (made by the celebrated ʿĪsā ibn Allāhdād of Lahore *ca*. 1610—can this be genuine ?); and

(3) Gunther, *Astrolabes*, I, pp. 135-136 and Mayer, *Islamic Astrolabists*, p. 49 (made by Ibrāhīm ibn Sharaf al-Dīn Ḥusayn for ʿAbd al-Razzāq al-Gīlānī in Meshed in the year 1641).

See already North, "Hour-Line Ritual", p. 114, on the defects of the last of these (but it was not intended for latitude $56^1/_2$°, it was simply the work of an incompetent). Yet another example is the second of the four instruments listed in n. 11:14.

The Indian astrolabe mentioned in n. 11:9 has the same kind of axial markings.

[12] The earliest surviving example of such markings is the astrolabe from Isfahan, 496 H [= 1102/03], discussed in **XIIIc-11**. For a mid-12th-century example of *ẓuhr*- and ʿ*aṣr*-curves (for Rayy and Isfahan) with a linear solar longitude scale see Gunther, *Astrolabes*, I, pl. XXIV, between pp. 116 and 117, *Washington NMAH Catalogue*, pp. 62-64; *Linton Catalogue*, p. 83 (no. 161) and two plates.

in shape as in **Figs. XIIIc-8.1b**, **9i**, **13a** and **A2a**; later quadrants of this kind had stereographical solar scales and the curves were closer to—and generally drawn as—arcs of circles.[13] On Indo-Iranian astrolabes it was a custom to graph the meridian altitudes for a series of latitudes and the solar altitudes when the sun is in the azimuth of Mecca for a series of localities.[14] To avoid confusion the two sets of curves were related to two different axial scales for the solar longitude, one progressing from the winter solstice to the summer solstice and the other reversed. This was beyond some astrolabists, and they engraved the quadrant but simply left out the curves—see **Fig. 11.3b**.[15] To then add universal horary markings was simply not a good idea.

There are also three late instruments on which even the hour-curves are misrepresented. They have been drawn shallower than they should have been—see **Fig. 11.3e**;[16] in one case, each with the same radius like a "Catherine wheel"—see **Fig. 11.3f**.[17] The reader should bear in mind that the above are exceptions to the general rule that the hour-curves were drawn correctly. However, I am still looking for an Islamic instrument on which the hour-curves are adapted properly for a specific latitude.

Universal markings on astrolabic quadrants

As noted in **10.4**, a tradition of including a small set of universal markings on astrolabic quadrants, nestled within the main astrolabic markings for a specific latitude, continued as long as these quadrants were being made, that is, until about 1900.

11.4 European modifications to the universal horary quadrant with circular arcs

An elegant, ingenious, and simple modification of the paraphernalia of the universal horary quadrant is found on the back of a mid-14th-century English astrolabe (#296) belonging to Oriel College, Oxford, and now housed in the Museum of the History of Science—see **Fig. XIIa-7b**.[18] Here the quadrant is engraved within the full circle of the back of the instrument; the problem of the shadow-square, usually uncomfortably superposed on the hour-curves, is solved by marking the *shadow* on the quadrant scale. The *altitude* is marked on the circumference of the lower semi-circular rim of the astrolabe. Both scales are, of course, non-uniform. This combination of hour-curves and scales is unique amongst the known sources.

John North has already identified five European astrolabes in the Museum of the History of Science at Oxford alone on which the hour-curves on the universal horary quadrant have

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[13] See Michel, *Traité de l'astrolabe*, pp. 78-86, on the underlying theory.

[14] Gunther, *Astrolabes*, I, pl. XLI between pp. 160 and 161 (no. 76) shows four examples. See also King, *Mecca-Centred World-Maps*, pp. 186-191, for more, and a detailed discussion.

[15] On #54 see *Washington NMAH Catalogue*, pp. 93-95 (no. 54), and for two others see Gunther, *Astrolabes of the World*, I, pls. XLII-XLIII, between pp. 166 and 167.

[16] #112 (London, British Museum, inv. no. 64 12-21 1) is unpublished. For another instrument by the same maker preserved in Haifa see Brieux, "Rare Islamic Astrolabe".

[17] On #76 (Oxford, Museum of the History of Science, inv. no. ?) see Gunther, *Astrolabes*, I, p. 208 (no. 76).

[18] On #296 see Gunther, *Early Science in Oxford*, II, p. 206 (no. 176), and *idem*, *Astrolabes*, II, p. 473 (no. 296) and pl. CXXXa; also Poulle, *Instruments astronomiques*, 1983 edn., p. 18.

been adjusted for some particular latitude. As an example of one of these one may cite the French astrolabe of 1595 owned by Philis de Din.[19] The plates of the astrolabe serve Paris (48°) and Lille (51°) and the two quadrants on the back for seasonal and equinoctial hours serve 50°, a happy combination. The non-uniform solar longitude scales are marked on the alidade.

Another European modification is displayed on the horary quadrants of Peter Apianus, illustrated in his treatise on the quadrant published in Ingolstadt in 1532—see **Fig. XIIa-13b**.[20] In addition to the main markings, cunningly contrived to display the equinoctial hours for a series of latitudes, there is a universal quadrant for the seasonal hours on which the markings for hours 1 to 5 have been drawn as arcs of circles with a slight sigmoid flourish at their ends. I suspect that this is purely aesthetic since the outer extremities of the markings were not necessary for timekeeping in European latitudes. On both German and Dutch horary quadrants from *ca*. 1700,[21] the ends of the hour-curves have been clipped off altogether to serve the same latitude for which the main markings display the equinoctial hours.

An instrument described by Apianus as part of a torquetum is the *semissis*. It consists of a semi-circular vane held vertically with diameter horizontal in the plane of the sun; on one side are two universal quadrants side by side with the two sets of curves emanating from the centre. According to Robert T. Gunther, there are 14th-century English manuscripts describing the same device.[22]

Again the medieval English *navicula de Venetiis*, "little ship of the Venetians",[23] a special kind of universal horary dial, whose conception, not necessarily in the form of a ship, I strongly suspect is to be associated with 9th-century Baghdad, bears on the back side a universal horary quadrant next to a shadow-square—see **X-9.1** and a detailed discussion in **XIIb-9a-c**.

There are European manuscript examples, as well as Islamic ones, where hour-curves have been drawn by an incompetent (see **Fig. 9.1c**), although I have located such curves only on one actual instrument: see **Fig. XIIa-2d**.[24]

Apart from these minor modifications, European *universal* horary quadrants remained in principle unchanged until about 1700, when the last quadrants of any kind were being made.

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[19] North, "Hour-Line Ritual", p. 114, on Gunther, *Astrolabes*, II, pp. 359-361 (no. 211).
[20] Already featured in Zinner, *Astronomische Instrumente*, p. 161. On Apianus see n. 8:16.
[21] For a Dutch example see van Cittert, *Utrecht Astrolabes*, pp. 33-35, and pl. XVIII, and Viladrich, "Horary Quadrants", p. 345.
[22] Gunther, *Early Science in Oxford*, II, p. 37.
[23] Several examples are described in Brusa, "Le navicelle orarie di Venezia"; see now **XIIb**.
[24] #3000—Basle, Historisches Museum, inv. no. ?—unpublished.

CHAPTER 12

CONCLUDING REMARKS

Since our formula was surely adopted from pre-Islamic Iranian or Indian sources, and since universal horary quadrants were still being drawn on other instruments in the 18th and 19th centuries, I can claim that this formula found applications for over a millennium.[1] The universal dials of al-Marrākushī and Najm al-Dīn al-Miṣrī, which, at least in the case of the former, surprisingly seem to have had little influence in the Islamic world, would surely have been popular in Renaissance Europe had they been known there, for European astronomers also liked universal solutions even though they were somewhat less adept in developing them than their Muslim counterparts.

I are well aware that in relating the fates and fortunes of an individual formula I have strayed from the traditional mode of investigation of medieval scientific materials, but I am convinced that this is a valid mode of presentation in this particular case. I felt it necessary not only to draw attention to the formula and its applications, but also to differentiate clearly between various types of quadrants confused in the recent literature.

In the days when the only known Islamic astrolabic quadrants dated from the 14th century it was not unreasonable to suspect that the Muslims took the clever notion of the quadrant with stereographic representation of ecliptic and horizon from the Europeans. But unfortunately the two different instruments were confused, and this confusion now seems firmly established in the literature (see now **X-6.3** and **6.5**). I urge greater precision in the description of such instruments in the future, and suppression of the completely false implication that the Muslims inherited the astrolabic quadrant from Europe.

Now that the Islamic material is under better control, it would be useful to have a new history of the quadrant in Europe, combining the English and continental traditions. I hope that some colleague with more facility with the European sources will consider embarking on this worthwhile undertaking.

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[1] See **IV** for another approximate formula of Indian origin, this time arithmetical, that was highly influential for over a millennium, not least because its use was implicit in the definitions of the daylight prayers which became standard in Islamic practice, some of them being used until this day.

APPENDIX A

SELECTED RELEVANT TEXTS IN TRANSLATION

Note: Only texts relating directly to the formula are presented here. Words and passages underlined are not fully intelligible to us. Editorial remarks are between curly brackets. For references to the treatises of al-Marrākushī and Najm al-Dīn al-Miṣrī the reader should consult Sédillot-*fils* and *père*, and Charette, respectively.

1 al-Bīrūnī on the *Hārūnī Zīj* and Yaʿqūb ibn Ṭāriq

al-Bīrūnī, *Shadows*, pp. 138, 159 (misplaced), 147;
cf. Kennedy, *al-Bīrūnī's* Shadows, I, pp. 187, 196, 198.

Chapter 26 on determining the time of day elapsed (since sunrise) or remaining (until sunset) by shadows. ... ... Our aim here is (to present) that which is connected with the determination of (the time) by shadows, whether it be accurate or approximate.

... ...

I read in the *Zīj* called *al-Hārūnī* that if the hypotenuse of the shadow (*quṭr al-ẓill*) of midday is multiplied by 150 and the product divided by the hypotenuse of the shadow at the time of measurement, and the corresponding arc taken in the (table of) *kardaja*s and their Sines, and one hour (reckoned) for each *kardaja*, then (the result) will be the number of hours passed (since sunrise) or remaining (until sunset) ... ...

Yaʿqūb ibn Ṭāriq favoured a similar (procedure) when he stated: "Divide 1800 by the hypotenuse of the shadow at the time (in question) and mutiply the quotient by 150 and divide the product by the Sine of the meridian altitude. Find the arc corresponding to the resulting Sine and reckon for each 15° of it one equal {*sic*} hour. ... ... "

2 al-Khwārizmī on the simple trigonometric quadrant

MS Berlin Ahlwardt 5793, fols. 96v-97v

(An extract on) the construction of a quadrant from which can be found the Sine and the declination and the hours of daylight elapsed. ... ... If you want to construct this quadrant take with God's blessing and His aid a quadrant of ... ... {hole in text (two words ?)} at a right angle derived from the circle of a division plate (*dāʾirat ṣafīḥat al-qisma*), then divide it into ninety degrees and divide (the radius) from the centre to the end of the ninety degree (scale) into one hundred and fifty equal parts—this is the Sine. Then suspend at (the centre) a thread and plummet. Next mark the Sine of each degree on the Sine (axis) as has been tabulated (*maʿmūl*) in the table {there is no accompanying Sine table, possibly because we are dealing here with an extract from a longer treatise}. (The Sine) can be derived accurately from the

table on which is written “Table of the Sine” and the way to do that is to take the Sine of [each?] five (?) (degrees) altitude, find its Sine, and mark it on the quadrant on the plate as you see illustrated. Know this if God Almighty wills.

A description of the use of this quadrant once it has been constructed... ... ... If you want to find how many hours of daylight have passed, see what is the altitude at midday on the day in question. If it were 60 (degrees) we should find that this corresponded to the fifth circle, that is, the line which goes out from the end of the ninety (scale) which is the Sine of the circle of degrees: it is the one with Sine equal to 130 {correctly 129;54}. If the altitude at the time of measuring is 30 (degrees), the thread corresponds to a certain place on the fifth circle, so we go out in its direction towards the place of the altitude and we find it on twenty-five {actually thirty-five !!} (degrees) and (some) minutes. Thus we know that one and two thirds and a fraction of an hour of daylight have passed because each15 (degrees) of altitude correspond to one hour. ... ... If you want to work with a Sine to (base) sixty, divide the Sine (scale) of the quadrant into sixty (parts instead).

3 Anonymous treatise on the horary quadrant for a specific latitude

MS Istanbul Aya Sofia 4830, fols. 196v-197r

I have made for you a table for the altitude of the hours in the signs and the middles of (the signs), so use it. If you wish to perform the operation with the altitude of the hours, that take the Sine of Cancer in the climate which you are in and keep it in mind. Then take the first kardaja of the Sine and multiply it by the Sine of the beginning of Cancer and divide (the product) by one hundred and fifty. The result will be a Sine: convert it to an arc, and this will be the altitude at the first hour of Cancer, so keep it in mind. Then take the first and second kardajas and multiply each by the Sine of midday and divide them by one hundred and fifty. Take the arc of the result and this will be the altitude at the second hour. Then take the first, second, and third kardajas and do the same with them: the result will be the altitude at three hours. Likewise, the fourth, fifth and sixth. Do for the other signs as you did for Cancer, similarly for all the signs. If you want, also take fifteen degrees and make it a Sine, multiply the result by the Sine of the altitude at midday in Cancer and divide the product by one hundred and fifty. (Then) make the quotient an arc: this will be the altitude of one hour of the hours of Cancer. Then take thirty (degrees) and do the same with it, up to ninety. The results will be the (altitudes) of the hours of Cancer. Then do the same for the remainder of the signs. I have made the table and the illustration for you. Understand that.

4 Anonymous Abbasid treatise on quadrants

MS Cairo DM 969,4, fols. 8v-9v (compare **XIIa-A**)

A treatise on the use of the quadrant. A statement concerning the use of the quadrant (*rubʿ al-dāʾira*). These are its chapters:

(The first chapter) on its markings (*khuṭūṭ*) and their names. The quadrant is a quarter of a complete circle. The first of its markings are the two lines that intersect at the centre, one

of which is called the east line and the other the line of the meridian (*khaṭṭ nihāyat al-irtifāʿ*). In between these two lines around the circumference of the quadrant there are equal divided parts which are ninety degees. These are called (the place for) the cursor (*al-majarra*, *sic* for *al-majrā*) and (the cursor) is made moveable in some quadrants and fixed in others. Below these, there are six curved lines that are segments of circles called the seasonal hours. These lines are made straight in some quadrants and in others radii (text: diameters) radiating from the centre of the quadrant. The use of all of these is the same.

Then there is the square for the shadow: each side of the sqare is divided into 12 parts, the side by the meridian is the horizontal shadow, the other side the vertical shadow. At the head of the quadrant there are two extra parts called the sights with two holes. A thread bearing a plummet extends from the centre of the quadrant, also bearing a moveable knot (!) called the marker (*al-murī*). These are the markings on the quadrant: so know this.

(The fourth chapter) on finding the time of day elapsed in seasonal hours ... ... at any time (of the year). If you want this, place the thread on your day on the cursor and then move the marker until you place it on the meridian line that is the [sixth] line. Then if you adjust it, the altitude of the sun is fixed as (described) previously. Now look where the marker has fallen on the hours, and this will be the hours of daylight passed if the sun is in the east. ... ...

(The ninth chapter) on the latitude of the locality. ... ... Know that the movable cursor should not be fixed until it is set for the latitude of the locality. The (fixed) cursor is made for a specific latitude ... ... and the latitude for this cursor is 33° ... .

5 An anonymous author (Ḥabash ?) on the duration of twilight

MS Berlin Ahlwardt 5750, fol. 153v—see **5.0**

"The determination of daybreak and nightfall. If you want (to find the duration of) daybreak and nightfall multiply the Sine of 18° by the total Sine and divide the product by the Sine of the meridian altitude of the point of the ecliptic opposite the sun. This will be a Sine for which you find the corresponding arc and divide it by 15°. The quotient will be hours and minutes, (the duration) of nightfall in seasonal hours. Subtract this from 12 hours: the remainder will be (the time from sunset) to daybreak ... ."

6a Ibn al-Zarqālluh on the use of the *ṣafīḥa*

Puig, *Al-Šakkāziyya* (see n. 2: 15), p. 33 (Arabic text), p. 115 (Spanish)

The twentieth chapter on finding the seasonal hours of daylight elapsed from the altitude of the sun in the meridian. ... ... This operation is approximate. God knows best.

6b Anonymous Egyptian on the *shakkāziyya* quadrant

Samsó, "Cuadrante šakkāzī" (see n. 8:12), especially p. 120,
based on MS Cairo DM 64

If the sun or a star has declination, place the thread at the meridian altitude corresponding to the solar longitude on the quadrant scale. (Then) mark with the bead the declination circle (*madār*) corresponding to the observed altitude. Next move the thread to the *madār* of the equator (that is, the horizontal axis) and make a note of how many meridian curves the marker crosses {it would be simpler to say: measure the arc traversed on the quadrant scale}. If you wish (!) reckon for each 15 degrees one seasonal hour passed since sunrise if the altitude is in the east, or remaining until sunset if it is in the west. The fractional parts will be fractions of one hour.

7 Ibn Isḥāq on the approximate formula

MS Hyderabad Andra Pradesh State Library 298 (unfoliated), Chs. 26 and 42

Chapter 26 on the determination of the ascendant and midheaven from the hours of day and night, and the time from the ascendant, and on the operations of timekeeping by day. ... ...

If you want the altitude of the sun in terms of the number of hours of daylight passed, take the hours if it is before midday, and work with them. If it is after midday subtract them from 12 and use the remainder. Multiply the amount by 15 and take the Sine of the product. Multiply it by the Sine of the solar meridian altitude and divide (the product) by 60 and take the arc (Sine) of the quotient. The resulting arc will be the altitude of the sun at the time in question.

... ...

Chapter 42 on an explanation of some of the tables in this *Zīj*. A treatise on the table of evening and morning twilight (with argument) from 31° to 90°. If you want to work with this table enter with the (meridian) altitude of the opposite point of the ecliptic in the column for the altitude and (the corresponding entry) will be (the duration of) evening twilight at that time (of year). If you subtract it from 12 the remainder will be (the time from sunset to) daybreak, if God Almighty wills. (Alternatively we can use) the calculation on which the table is based. Multiply the Sine of 17°, which is 18;32,59 by the total Sine, which is 60, and the result will be 1112 and 59 (sixtieths). Divide this by the Sine of the solar meridian altitude for [the point of the ecliptic opposite !!] that solar longitude and the result after taking the arc corresponding to the quotient will be (the duration of) evening and morning twilight for that (solar) longitude. Make each 15° an equal (??) hour, and this will be what you wanted.

8 Extracts from an anonymous 12th-century (?) Andalusī (?) treatise on horary quadrants

MS Cairo ṬM 155,3, fols. 19r-21v

An approximate method is that you open the compass so that if you put one of its legs on the line of the centre and the other at the centre of the quadrant, (draw arcs,) and keep in mind which of them passes through the six equal divisions into which the above-mentioned (altitude) scale is divided; you keep doing this until the six hour lines are completed ... .

... ... This kind of shape can be made universal by marking any point on the line of rising and setting (viz., the horizontal axis) preferably at a medium distance from the beginning

of the quadrant scale and from its centre and drawing a straight line to the end of the quadrant which will be the end of the sixth (hour). Then you put the ruler on each ten (degrees) of the altitude scale and on the centre of the quadrant and you make a mark at its intersection with the line of the maximum altitudes and join these marks and the common point with straight lines which are the day-circles of the maximum altitudes. You mark the hours on them using the altitudes of the hours on the maximum altitudes as you marked them on the day-circles using the altitudes of the hours of the day-circles ... .

LIST OF MANUSCRIPTS CITED

Note: An asterisk indicates that I have not consulted the manuscript in question or a microfilm thereof. For catalogues of Arabic manuscripts see Sezgin, *GAS*, VI, pp. 295-466.

LIST OF INSTRUMENTS CITED

Part XIIa

On the universal horary quadrant for timekeeping by the sun

In memory of Frans Bruin

DEDICATION,
ACKNOWLEDGEMENTS AND NOTES TO THIS VERSION

This study is dedicated to the memory of Frans Bruin (1922-2001), a scholar with a unique understanding of ancient and medieval astronomical instruments, who did much to arouse my interest in them. He was well known to a small group of historians of astronomy, principally those associated with the school of Otto Neugebauer, for his knowledge of ancient and medieval observations, partly based on his own experience in trying to observe celestial phenomena in the same way as did the astronomers of Antiquity and the Middle Ages. In addition to a few important publications in the history of practical astronomy Frans produced a series of papers, the *Biruni Newsletters*, mimeographed and circulated privately, which deal with different themes in the history of observational and theoretical astronomy.

In 1970-1971, when my wife and I lived in Beirut, Frans came to our apartment once a week to help me in my study of Ibn Yūnus' observation reports and to join us for dinner. Frans had erected a fine armillary sphere on the roof of the Physics Department at the A.U.B. (see **Fig. 1**), and it was impressive to watch the shadow of the upper part of the equatorial ring move over the lower part at an equinox (see Newsletter no. 8 and 16). Frans also set up a small room near his house at Kfour as an "ancient observatory". Here he had a series of architectural features and instruments and made observations (see **Fig. 2** and Newsletter no. 1).

I also had the pleasure of numerous conversations with Frans during the years of his secluded retirement in southern England. In spite of various physical handicaps, Frans never lost either his enthusiasm for instrumentation, which was but one of his interests in the history of science and in modern science. An obituary notice is in *Journal for the History of Astronomy* 33 (2002), pp. 214-216, but, for reasons of space, this was shortened from a longer version I had prepared. Here I include a list of Frans Bruin's publications dealing with the history of astronomy:

1967: "L'eclipse d'Hipparque et les grandeurs et distances de la lune et du soleil", *Orion*, vol. 12, pp. 50-54; **1971**: *The Books of Autolykos* (with A. Vondjidis), Beirut: A.U.B.; **1976**: "The Equator Ring, Equinoxes and Atmospheric Refraction" (with M. Bruin), *Centaurus*, vol. 20, pp. 89-111; **1977**: "The Limits of Accuracy of Aperture Gnomons" (with M. Bruin), in *ΠΡΙΣΜΑΤΑ—Naturwissenschaftsgeschichtliche Studien—Festschrift für Willy Hartner*, Y. Maeyama and W. G. Saltzer, eds., Wiesbaden, 1977, pp. 21-42; **1979**: "The First Visibility of the Lunar Crescent", *Vistas in Astronomy*, 21 (1979), pp. 331-358.

The *Biruni Newsletters*, of which copies are available at the Jafet Memorial Library of the American University of Beirut; the Department of the History of Science and Medicine at Yale University; the Institute for the History of Science at Frankfurt University; and the Institute for History of Mathematics at Hamburg University, are entitled as follows:

1965 (1) Plans for the Biruni Observatory; **1966** (2) On the observations of Hipparchos in Nicaea and Rhodos; (3) The making of an astrolabe; (4) The Tower of Winds in Athens; (5) The eclipse of Hipparchos and the size and distance of the moon and the sun; **1967** (6) Measurements in the prime meridian; (7) The shaking minarets of Isfahan; (8) The equatorial

Fig. 1: Frans Bruin and his armilla.
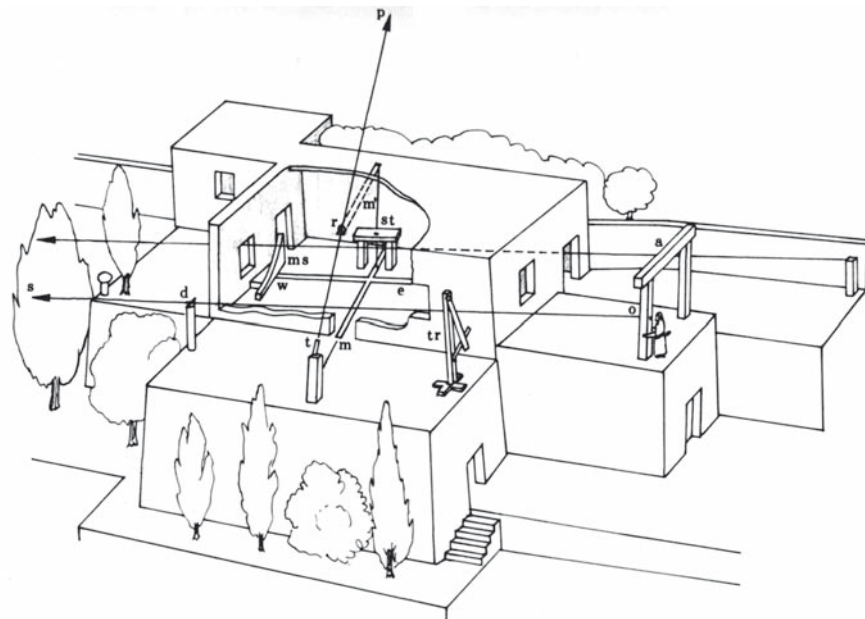
Fig. 2: Cut-away view of what Frans Bruins called his “Arab observatory” in the village of Kfour on Mount Lebanon at altitude 700 metres described in his own words: “m marble meridian strip of sundial on inside floor; m’ the same on the roof; ew east-west strip used during equinoxes; ms mural sextant of 3 metre radius; st stone table with reference point; t sighting tube; r small ring on the roof close to orifice of sundial; trp line of sight to Pole Star; d short brass ruler on pillar being one degree when viewed from o (the distance od is 16 metres); d is used as artificial horizon for setting sun at equinoxes; a frame for alt-azimuth instrument; tr triquetrum.”

ring; (9) The astronomical observatory of Ulugh Beg in Samarkand; **1968** (10) The observational instruments of al-Urdi; (11) al-Battani's chapter on the construction of the globe, the quadrant, and the ruler for astronomical observations; (12) The outflow clepsydra; (13) The astronomical observatory of Nasir al-Din al-Tusi in Maragheh; (14) The astrolabe with rings; (15) The construction of instruments used for the correction of astronomical tables by Abd al-Munim al-Amili-i Fotuni; **1969** (16) The equatorial ring, pt. 2; (17) The eye and the sky; (18) The first visibility of the lunar crescent; (19) The Fakhri Sextant in Rayy; (20-21) Astronomy and Physics at AUB; (22) Ptolemy on atmospheric refraction in his fifth book on optics; (23) The Hindus and al-Battani on the first visibility of the lunar crescent; (24) The heliacal setting of stars and planets; (25) The Observatory of Cairo; **1970** (26) Precise astronomy in Egypt. Was there any?; (27) The gnomon and Indian circle before 900 AD; (28) Aperture gnomons and Continental Drift; (29) The instruments of Taqi al-Din in the Observatory of Istanbul; (30) A treatise on small instruments by Abd al-Rahman al-Khazini of Khurasan (1150 AD); (31) Surveying and surveying instruments being Chapters 26, 27, 28, 29, and 30 of the book *On Finding Hidden Water* by Abu Bakr Muhammad al-Karaji (1029 AD); (32) The Hipparchean Diopter and the sizes of the planets; (33) The planispheric astrolabe, its history, theory, and use. Ch. 1: Description of the instrument and review of the literature; Ch. 2: History of the instrument; (34) The planispheric astrolabe, its history, theory, and use. Ch. 3: Astronomical background; Ch. 4: Some astrological concepts; (35) The planispheric astrolabe, its history, theory, and use. Ch. 5: Theory of the instrument; (36) Astronomical observations before Ptolemy; **1971** (37) Ancient measures. Units of length, volume, weight, and time, as related to astronomy; (38) Planetary motion (extract from lecture notes); **1973** (39) The Creation of the Universe. Historical introduction; (40) The Creation of the Universe.

Frans was extremely generous to those people at all levels of society whom he respected but could not suffer fools lightly. For encounters with both groups, he was richly blessed with a good sense of humour. He gave readily of his knowledge to serious students, but, for the reasons just explained, seems to have been engaged in an ongoing battle against the administration of the A.U.B. He much enjoyed telling the story of the young astrophysicist colleague who tried to hijack his Observatory from him. But there were four other stories about Frans Bruin that should go down in the annals of the history of astronomy.

1. When he had been commissioned to make a sundial for the campus garden by the President's wife, he was horrified to find that his sundial was to be purely ornamental and to be situated in a place where it would not enjoy the faithful Lebanese sun. His opinion about this matter was written on a paper preserved in a metal box in the cement of the base of the sundial.
2. Frans had an aperture gnomon in the ceiling of his living-room at Kfour. For over three years he had been marking the images of solar equinoctial and solstitial meridian passages in chalk on the marble floor (a continuation of the observations described in *Newsletter*, no. 6). Shortly before the 48th month of his observations, his Dutch mother-in-law came for a visit. The first thing she did upon arrival was to wipe up the "mess" on the floor. I am not aware of a printed version of Frans' reaction.

3. One day a Lebanese boy scout came to the Observatory and wanted some information for a project. Frans was happy to help him, but asked a favour in return. Could the lad kindly go to the Mufti's Office in Beirut to ask how they regulated the lunar calendar, especially the beginning and end of Ramadan. (The determination of lunar crescent visibility was one of Frans' favourite research topics, and one in which he was involved on a regular basis with his own calculations and predictions.) The boy returned a week later and reported that the Mufti's office took their information from the Meteorological Station at the Airport. Frans produced the bus-fare and asked the lad to go to continue his investigations out there. A week later, the boy returned with the surprising news that the Meterological Station got their information from the Observatory at the American University of Beirut. Thereupon Frans asked his assistant if he ever heard from anyone at the airport, whereupon he was informed that, yes, they called regularly every month and were supplied with Frans' predictions for the next month.
4. Frans had, of course, computed his own horoscope, necessarily according to Ptolemaic astrological prescriptions. He had predicted, amongst other things, that he would die a quiet death. In 1964, whilst passing through Grand Central Station in New York City, he was much amused by a computer-generated horoscope based on modern astrological prescriptions, which he purchased for a few dollars. According to this, he would die a violent death. Fortunately, although perhaps only because Frans fled his beloved Lebanon, it was the Ptolemaic horoscope that turned out to be right. It was only his armillary sphere that was blown to bits by tank fire.

In this study I have inserted some material from my earlier study of the approximate formula (**XI**) and have moved some of the illustrations from there to here. A shorter version of **Sections 1-4** of this study is in "A *Vetustissimus* Arabic Treatise on the *Quadrans Vetus*", *Journal for the History of Astronomy* 33 (2002), pp. 237-255. It is my hope that these various studies will put an end to the continuing misrepresentation of the universal horary quadrant in the modern literature, and that they will inspire a new investigation of the relationship between the Baghdad treatise, the treatise in the *Libros del saber*, and the various Latin texts.

TABLE OF CONTENTS:

1 Introduction

"Ce procédé (des lignes horaires) qui n'est rien moins que géométrique, pouvait fournir une approximation passable en Arabie, où les heures temporaires différaient très peu des heures équinoxiales. Sacrobosco n'a pas vu qu'en le transportant en Europe, il le rendait d'autant plus inexact, que la latitude était élévée. Sacrobosco nous décrit cette construction sans aucune réflexion, et nous donne ainsi la mesure de ses connaissances mathématiques. Si elle vient des Arabes, on peut dire qu'elle n'est guère digne d'eux ... ." Jean-Baptiste Delambre, *HAMA* (1819), p. 247.

"The *quadrans novus* was entirely different from the *quadrans vetus*; it was far more complex, being meant to be of the same service as the astrolabe." George Sarton, *IHS*, II:2 (1931), p. 851.

"In its simplest form the quadrant is a device for measuring the sun's altitude directly. ... ... The quadrant can be adapted to read hours directly by providing it with a suitable scale of dates and a set of hour-lines; it is then termed a *horary quadrant*." F. A. B. Ward in *London BM Catalogue* (1981), p. 53, taken from the notes of Derek de Solla Price. [Possibly it was Price who started the modern fiction that the universal horary quadrant must be fitted with a solar scale.]

"Dès le XII^e siècle, le quadrant (ancien) fut donc perfectionné par l'adjonction d'un curseur, capable de founir la hauteur méridienne nécessaire sans qu'il fût besoin de l'avoir observée." Emmanuel Poulle, "Les instruments astronomiques du moyen âge" (1967 Paris edn.), p. 18.

" ... the (universal) horary quadrant was the result of an adaptation—one of great geometrical ingenuity—of an instrumental solution of (the approximate) formula ... , which is an approximation of the true formula. ... ... How the formula was arrived at and who invented the instrument remain unknown to us." Richard Lorch, "Universal Horary Quadrant" (1981), p. 119.

"At best, the lines (on the back of an astrolabe) can give the unequal hour with an accuracy only about half as great [!!] as that given by the conventional astrolabe itself. At worst, the lines are carelessly drawn, unnumbered, very small indeed, and—worst of all [!!]—not associated with an auxiliary scale of solar positions. ... ... Not a single medieval (astrolabe) has survived in a form which would suggest that the unequal-hour lines were used meaningfully." John North, "Hour-Line Ritual" (1981), pp. 113-114.

"But if the *quadrans novus* had a relatively short life in the West, it endured far longer in Islam [*sic*]. From at least the 17th century onward in the Ottoman empire an attractive form of quadrant was produced in lacquered wood, which included a Prophatius quadrant on one of its two faces [*sic*]. (It) ... continued in use until the early 20th century. ... ... Throughout all this time, however, the instrument showed neither change nor refinement [*sic*]." Anthony J. Turner in *Rockford TM Catalogue* (1985), pp. 205-206.

"Although (the unequal hour diagram) was to become common on later astrolabes, especially European ones, it seems to have been of little service (*sic*) and surviving examples on astrolabes are frequently useless (*sic*)." Anthony Turner, *Mathematical Instruments in Antiquity and the Middle Ages* (1994), p. 77, n. 91. [Turner then recommends to his readers the study by Richard Lorch cited above, and "for the uselessness of surviving examples", the ill-fated study by John North.]

"The medieval tract on the quadrant called *Quadrans vetus* ... has given rise to a vigorous interpretative debate. Amongst the issues disputed are the author's name and the date of composition ... . Was it written after the mid-thirteenth century, or perhaps as much as a century earlier? The classical pronouncements by eminent scholars like Paul Tannery, Pierre Duhem, José Millás y Vallicrosa, and Lynn Thorndike have been scrutinized in recent studies by Emmanuel Poulle, Steven K. Victor and Nan L. Britt Hahn." Wilbur Knorr, "*Quadrans Vetus*" (1997), p. 23.

"One thus lacks a firm precedent for an understanding of the calibration of the cursor before the thirteenth century." *Idem*, "Sacrobosco's *Quadrans*" (1997), p. 213.

"The universal horary quadrant ... was an inferior device for reckoning time from solar altitude, giving approximate values in planetary hours." Gerard L'E. Turner in *Christie's London 08.04.1998 Catalogue*, p. 73 *ad* lot 49 (#256).

"Also on the back (of the *navicula*) is an unequal hour quadrant for converting time in equal hours found by the sundial [*sc*. the universal horary dial on the front of the *navicula*] into unequal or planetary hours." Jim Bennett, "Oxford *Navicula*", on EPACT website.

"(The *quadrans vetus*), designed to measure heights, distances and depths, could also be used as a universal sundial." Anthony J. Turner, "Florence *Quadrans vetus*", on EPACT website

"I am said [by King] to have claimed that the universal horary quadrant is "essentially non-functional", and that this is a misunderstanding. It is indeed a complete misunderstanding of what I actually wrote, but more to the point, it heads in no detectible direction except that of fending off an imagined slight to early Islamic science." John North, "Review of King, *Mecca-Centred World-Maps*" (2000), col. 750 *ad* p. 351, n. 91.

"The quadrant (on the back of the *navicula*) can be used with the sights both to measure the angular height of any object and to show the planetary hours of the day." Hester Higton in *Greenwich NMM Sundial Catalogue*, p. 250.

"The *quadrans vetus* ... probably had its origins in Arabic countries, where examples have been dated to the eighth century [*sic*]. ... (Adjusting the quadrant) for the correct date and latitude ... ... (is) a rather complicated process. ... ... After this rather longwinded setting-up process the quadrant is ready for use. ... ... This is quite a laborious for finding the time, but the end result was usually more accurate than that given by pillar dials or ring dials." Hester Higton, *Portable Sundials* (2001), pp. 22-23. [Setting up the instrument for the right latitude and date would have been trivial for any medieval astronomer. The author neglects to mention that one must then set the bead on the curve for the sixth hour before sighting the sun. The result is indeed approximate, but would be less accurate than the results from properly-made vertical dials or ring dials.]

The universal horary quadrant is an ingenious mathematical device which was used in one form or another for close to 1000 years,[1] yet its first mention in the primary sources is not generally known, and the function for which it was intended, in the rare cases where it is mentioned, has sometimes been misunderstood in the modern secondary literature.[2] Its function was, for any reasonable terrestrial latitude and at any time of the year, to find the time of day in seasonal hours[3] from the altitude of the sun and its meridian altitude; it is based on an approximate formula that works better than one would expect at first encounter. Because of its simplicity and efficacy, the universal horary quadrant in its different manifestations became, after the astrolabe, and insofar as one can separate it from the astrolabe,[4] the second most widely-produced instrument in the Middle Ages, at least in Europe if not in the Islamic world.[5] In

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[1] See King, article "Rubʿ" [= quadrant] in EI_2, VIII (1995), pp. 574-575 and 4 pls., and **X-6**, for overviews of the early history of the different kinds of quadrant in the Middle Ages. The Baghdad treatise was announced already in King, "Review of Sezgin, *GAS*, VI", p. 59. The findings of this paper are summarized in *idem*, "Neglected Astrolabe", pp. 48 and 51-52, and *idem*, "Astronomical Instruments between East and West", p. 165. The text and translation of the Baghdad treatise are published in *idem*, "A *Vetustissimus* Arabic Treatise on the *Quadrans Vetus*", *JHA* 33 (2002), pp. 237-255.

[2] In the modern literature the best overview of the markings and their history is Archinard, "Unequal Hour Diagram". See also n. 3:1.

[3] The seasonal day hours of Antiquity and the Middle Ages are the one-twelfth divisions of the length of daylight; they are hence dependent on terrestrial latitude and solar longitude. By "reasonable" I mean sometimes sub-polar, sometimes non-tropical, and sometimes between *ca*. 25° and *ca*. 45°. On the astrological associations of the seasonal hours see n. 13:5.

[4] On the astrolabe see North, "Astrolabe", and King, "Neglected Astrolabe", expanded in **XIIIa**, the latter dealing, in particular, with the origin of some of the components.

[5] Note that I use the word "widely-produced" rather than "widely-used" or "widely-known". To what extent universal horary quadrants were used is a matter for debate, as is the extent to which the theory underlying their markings was understood.

the history of medieval instrumentation it went hand-in-hand with a shadow square—see further **App. B**.

I use the term "universal" to describe any astronomical instrument or table that works for essentially all terrestrial latitudes.[6] I use the expression "universal horary quadrant" because the markings are universal, the purpose solely to measure the time of day in seasonal hours, and the form usually a quadrant.[7] Other modern expressions, such as "unequal-hour lines", "unequal-hour diagram", "universal sundial", and "horary quadrant for planetary hours", let alone "le quadrant israélien ou judaîque", tend to obscure the function and the scope of the markings, as well as their origins. Likewise I use the expression "universal horary dial" to refer to the kind of markings found, *i.a.*, on the medieval instrument known as the *navicula* or the *Uhrtäfelchen* of Regiomontanus: they too are universal, they serve the determination of the (equinoctial) hours using the exact formula, and they consist of a set of fixed horary markings to be used in conjunction with an ingenious movable device with thread and movable bead attached with which one can enter the local latitude and the solar declination. This seems preferable to various other expressions in the modern literature, some with good historical backgrounds, such as "Uhrtäfelchen" or "cadran solaire rectiligne" or "rectilinear dial" or "universal sundial" or "universal altitude sundial". There is a sense in which the quadrant and the dial serve the same purpose: both serve essentially only timekeeping by the sun;[8] both are universal, but one is approximate and the other is accurate; one is very easy to use and the other requires some dexterity, especially to arrive at the exact solution.[9] There is a third universal device that has also had a chequered career in the Middle Ages as well as in the modern literature, namely, the universal horary markings sometimes found on alidades: see further **App. C**.

Hitherto, the first descriptions of the *quadrans vetus*, that is, the universal horary quadrant with movable solar longitude cursor, also provided with a shadow square, were known only from medieval European sources: in the present study, an Arabic text from 9th- or 10th-century Baghdad on the very same instrument is presented. I leave it to others to investigate the relationship of this "new" treatise to the later Latin texts; certainly the European tradition was

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[6] On universal instruments and tables see further **VIa-b**. Alas the universal horary quadrant was omitted from the earlier studies (first published in the 1980s and repr. in King, *Studies*, C-VI and VII) on which the new versions are based. On the concept of universality in relation to the standard astrolabe see *idem*, "Geography of Astrolabes", pp. 6-11 and 14-17, now in **XVI-2** and **4**.

[7] In some recent writings the purpose of the markings is said to be for converting time in equinoctial hours to seasonal hours.

[8] A more complex mathematical device is required for timekeeping for any latitude by the stars, since this also involves the sun and various kinds of stellar data must be accessible. Such a device was invented in Baghdad in the 9th century: see now Charette & Schmidl, "Ḥabash's Universal Plate", and now **XIIb-12**.

The universal horary quadrant can of course be used to find the time of night from the instantaneous and culminating altitudes of any star, but the time is then given in "stellar hours" related to the arc of visibility of the star in question. Only one medieval astronomer is known to me (**I-4.6.1**) who used such "hours".

[9] The correct use of the universal horary dial on the *navicula* is nowhere described in the modern literature. See further the parallel study to this one in **XIIb**.

derived from early Islamic sources, not least because the horary markings in both traditions are associated with shadow squares (see **App. B**). But there is another instrument we should consider as well, namely the *quadrans novus*, a late-13th-century European development of the *quadrans vetus* that included some astrolabic markings. The modern literature on the quadrant is cluttered with a confusion of the *quadrans novus* with the astrolabic quadrant, an Islamic invention quite different in conception.

The universal horary quadrant without a solar scale, which, like the shadow scales, is found occasionally on the backs of astrolabes, has been misunderstood by some modern authors as essentially non-functional without an additional solar scale: in this study I shall show that the basic markings even without the solar scale serve perfectly well the purpose for which they were intended. The correct procedure, which is beautifully simple, is very seldom (only once?) mentioned in the modern literature on the astrolabe.[10]

It is often overlooked that the universal horary markings provide a graphical representation of the altitude of the sun at the seasonal hours that is *approximate*. There is, however, no better way of representing graphically the solar altitude at the seasonal hours for all latitudes. If one wants to display graphically the solar altitude at the seasonal or equinoctial hours throughout the year for a specific latitude, one needs a different set of markings. Different ways of graphically representing the altitudes at either kind of hours for a fixed latitude were used by astronomers from the 9th century onwards;[11] I shall occasionally mention such latitude-specific quadrants. Also, in this study I shall carefully differentiate between approximate and exact solutions in spherical astronomy, and show that direct combinations of both are inappropriate. In the same way, it is not advisable to directly combine universal and latitude-specific solutions. Furthermore, my study shows clearly that to better understand instruments in their historical context, one should look not only at treatises on such instruments but also at the surviving instruments.[12]

Any attempt to seek the identity of some very clever person in the Islamic world who could have designed the universal horary markings, and to document in passing that others in Europe, perhaps not so clever, perhaps simply with less mathematical insight than their Muslim predecessor(s), often did not appreciate them or even overestimated them, runs the risk of turning into a kind of "cultural contest".[13] However, such an attempt seems to me appropriate in this case and at this time not least because of the frequent distortions in modern accounts of the universal horary quadrant and the *quadrans novus* and the incessant stream of modern publications on the origins of the *quadrans vetus* in the Latin sources.

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[10] See n. 9:7.

[11] See n. 2:3 on the earliest text, and Viladrich, "Horary Quadrant", for a preliminary overview. New insights are presented in Charette, *Mamluk Instrumentation*, II-3.1.

[12] The best account of any group of medieval European quadrants is still Gunther, *Early Science in Oxford*, II, pp. 156-181.

[13] This expression in the context of the history of medieval astronomical instrumentation was coined by John North (in "Review", col. 748).

Fig. 2a: The beginning and end of the text in the Cairo manuscript. [Courtesy of the Egyptian National Library, Cairo.] *Note added in second proof (Jan., 2005)*: I dated this manuscript to *ca*. 1800 in the late 1970s, but this needs to be checked. By chance, I came across a very similar script in MS Meshed Shrine Library 392+393 (formerly 5593+5521), copied at a Moghul court in 867 H [= 1462/63]. The manuscript is a miscellany of important early Islamic texts, including a unique copy of Diocles' *On Burning Mirrors*. It came to Meshed by the late 19th century. See further Toomer, *Diocles: On Burning Mirrors*, pp. 26-31 and 114-137 (facsimile of Diocles text). Maybe my dating of the Cairo manuscript was too late.

2 The Baghdad treatise and its author

Various forms of the universal horary quadrant are described in an Arabic treatise from 9th-century or, at the latest, 10th-century Baghdad. The text survives in a manuscript preserved in the Egyptian National Library in Cairo; this is a very late copy, prepared *ca*. 1800, probably in the holy city of Meshed in N. E. Iran: see **Fig. 2a.**[1] The surviving text is partially defective,

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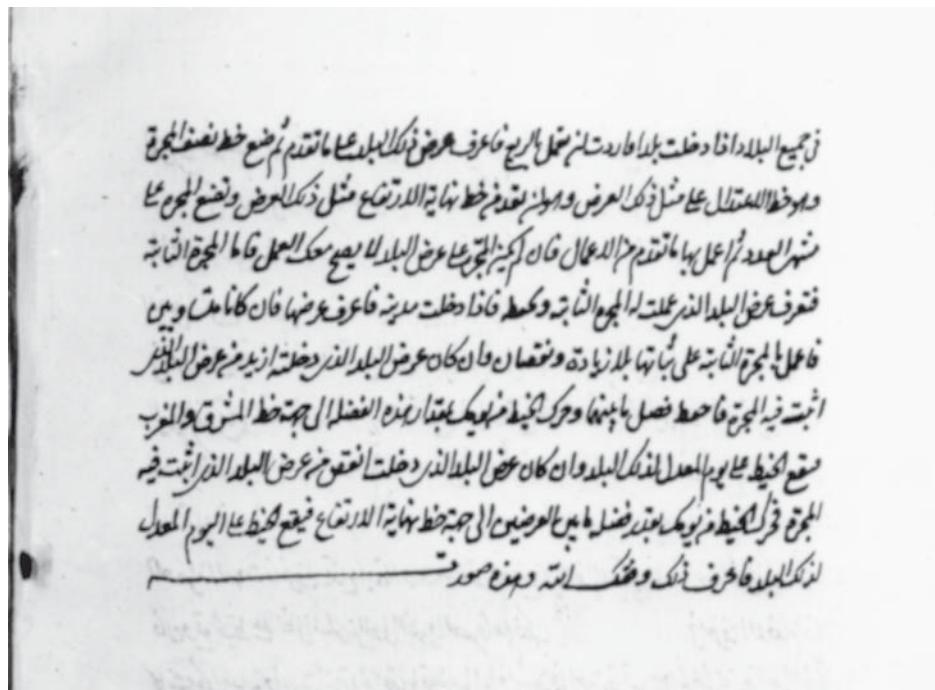
[1] MS Cairo DM 969,4, fols. 8v-9v, copied in an orderly but inelegant Persian hand. The manuscript, and also MS DM 970 by the same copyist *ca*. 1800, contains a series of important treatises on instruments from the 9th and 10th century, some, like this treatise on the universal horary quadrant, unique, and all unpublished. For details on the quadrant text see further *Cairo ENL Catalogue*, I, pp. 168-169, and II, pp. 540-541 (*ad* 4.6.12), and *Cairo ENL Survey*, p. 53 (no. B105) and pl. LIVa (caption on p. 207).

The treatises copied in MS 969-970 are the following:

(1) 969,1 (fols. 1v-2v): *Kitāb Dhāt al-ḥalaq*, "Treatise on the Armillary Sphere", by Daʾūd ibn Sulaymān—see *Cairo ENL Catalogue*, II, pp. 374-375 (4.2.1); *Cairo ENL Survey*, no. B28; not in Sezgin, *GAS*, VI; King, "Review", p. 59.

(2) 969,1a (fols. 2v-3v): *(Risāla) fī Naṣb dhāt al-ḥalaq wa-'l-ʿamal bihā*, "Treatise on Setting up the Armillary Sphere and its Use", anonymous, supplements (1), probably by the same author—see (1).

(3) 969,2 (fols. 3v-5r): *(Risāla fī) 'l-ʿAmal bi-'l-bayḍa wa-'l-kura*, "Treatise on the Use of the Celestial Sphere", by (*ʿan*) Abu 'l-Qāsim al-Munajjim, compiled in 287 H [= 900] in Jurjān—*Cairo ENL Catalogue*, II, p. 375 (4.2.2); *Cairo ENL Survey*, no. B29; not in Sezgin, *GAS*; King, "Review", p. 59.

II

but it is not difficult to reconstruct the author's intentions. In **App. A** I present the Arabic text, a translation, and a commentary.

The treatise is anonymous and I have wondered whether it is to be associated with the celebrated 9th-century astronomer Abū Jaʿfar al-Khwārizmī,[2] who also authored the earliest known treatises on the horary quadrant for a specific latitude and the sine quadrant.[3] The

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(4) 969,3 (fols. 5v-7v + 10v-14r): a fragment (*bāb*s 73-89) of a one *maqāla* of an anonymous treatise on the use of the astrolabe in at least 7 *maqāla*s (see fol. 12v)—*Cairo ENL Catalogue*, II, pp. 398-399 (4.3.9-1); *Cairo ENL Survey*, no. B102; not in Sezgin, *GAS*. The identity of the author of this substantial treatise remains a mystery: he is not al-Farghānī, al-Qūhī, al-Ṣūfī, Abū Naṣr, al-Bīrūnī, or one of the Andalusīs Abu 'l-Ṣalt, Ibn al-Samḥ or Ibn al-Ṣaffār. For other possibilities see various authors cited by al-Bīrūnī in his main treatise on the astrolabe (listed in Sezgin, *GAS*, VI, p. 268).

(5) 970 (42 fols.): anonymous treatise on the instrument called *al-āla al-shāmila*, actually due to the celebrated 10th-century astronomer and instrument-maker Ḥāmid ibn Khiḍr al-Khujandī—*Cairo ENL Catalogue*, II, pp. 545-547 (4.6.15); *Cairo ENL Survey*, no. B50; Sezgin, *GAS*, VI, p. 221, no. 1.

[2] On al-Khwārizmī see the *DSB* article by Gerald Toomer. Unfortunately this anonymous treatise was not mentioned in King, "al-Khwārizmī", a study of various treatises attributed to him discovered in the 1970s, mainly dealing with instruments.

[3] On his writings on the horary quadrant for a fixed latitude see King, "al-Khwārizmī", pp. 30-31. On his writings on the sine quadrant and the purpose for which he invented it, namely, to solve the formula underlying the universal horary quadrant, see *ibid*., pp. 27-29, and pp. 7 and 10-11, and for the text and a new translation, Charette & Schmidl, "al-Khwārizmī on the Astrolabe", forthcoming.

Of course, the universal horary quadrant of type 2 (see Fig. 2b) is nothing other than one variety of the sine quadrant (see n. 10:3). Richard Lorch ("Universal Horary Quadrant" and "Sine Quadrant") has stressed the origin
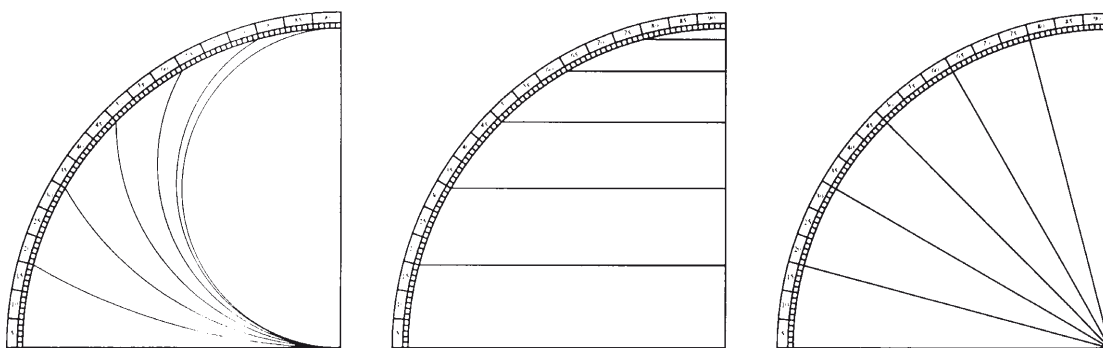
Fig. 2b: The three different kinds of markings mentioned in the Baghdad treatise.

Fig. 2c: The movable declination scale in a groove on the rim of the Baghdad quadrant of type 1, shown on a medieval European *quadrans vetus* (#5503). See also **Fig. X-6.2.1** for the *quadrans vetus* in Oxford (#5502), and **Figs. XI-10.2a-b** for the one in Vienna (#5505). [Courtesy of the Museo di Storia della Scienza, Florence.]

attribution of this treatise to the 9th-10th centuries is suggested first by the content, for it clearly predates the entire Latin *quadrans vetus* tradition. Furthermore, due attention is paid by the author to the determination of the times of the *ẓuhr* and the *ʿaṣr* prayers, associated here with the ends of the 6th and 9th seasonal hours (that is, midday and the middle of the afternoon),

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of the sine quadrant as a device for solving the approximate formula for timekeeping. See also Hogendijk, "Al-Khwārizmī's Sine of the Hours".

and the treatise is of prime importance since it represents a stage in the development of the Islamic prayer ritual *before* the standard definitions, in terms of shadow increases, were introduced; this process seems to have been achieved by the 9th century.[4] The association with al-Khwārizmī is suggested not least by the mention of the value 33° for the local latitude, which, in the light of our present knowledge of early Islamic astronomy, was only used by him in various minor treatises and can here only serve Baghdad.[5] Also it was used only in the 9th and 10th centuries. Furthermore, in the *summa* on astronomical instruments for timekeeping by Abū ʿAlī al-Marrākushī (*fl*. Cairo, *ca*. 1280), the sine quadrant is called *al-jayb al-Khwārizmī*, "the sine (quadrant) of al-Khwārizmī", and the shadow square *al-ẓill al-Khwārizmī*, "the shadow (square) of al-Khwārizmī".[6]

If al-Khwārizmī is the author, then this must be a later work of his, and he must surely have learned a great deal of trigonometry during his active life, for at least one of his early writings was heavy indeed, to the point of being somewhat absurd.[7] And it must be a later work of his than, say, his treatises on the construction and use of the astrolabe.[8] But he must also have learned a lot about the potential of Arabic as the new language of science, for the style is quite different from that of his astrolabe treatises.[9] Indeed, the language of the text is crisp and elegant, and no words are wasted. It is almost as if the work was, say, a 10th-, 11th-, 12th- or 13th-century recension of some 9th-century original.

Against the hypothesis of an origin in, say, the 11th-13th centuries, we note, besides the various points mentioned above, the fact that all of the other works copied in the same manuscript are most probably from the 9th and 10th centuries.[10] Certainly some version of the treatise ended up in al-Andalus before the 13th century, for it was surely in this way that the *quadrans vetus* came to the attention of Europeans in the 12th century. But most of the astronomical materials transmitted from the Islamic East to al-Andalus were of 9th- and 10th-century origin.[11] al-

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[4] On the times of prayer in Islam see the article "Mīḳāt, ii" [= astronomical timekeeping and the regulation of the times of prayer] in EI_2, and now **II**. See further nn. 2:8 and 2:16 and the commentary to Ch. 4 in **App. A**.

[5] On his use of this parameter, which is not particularly accurate, see King, "al-Khwārizmī", p. 2, and also *idem*, "Earliest Qibla Methods", p. 129. See further the commentary to Ch. 9 in **App. A**.

[6] On al-Marrākushī and the publications of the Sédillots *père et fils* see the article in EI_2, and now **II-2.7**.

[7] See King, "al-Khwārizmī", pp. 10-11, on some mysterious tables by him entitled *jayb al-sāʿāt*, "sine of the hours", and the rather surprising explanation in Hogendijk, "Al-Khwārizmī's Sine of the Hours", repeated in **XI-9.3**.

[8] A German translation of the treatise on the *use* of the instrument was published by Joseph Frank in 1922. Brief remarks on the treatise on the *construction* of the instrument are in King, "al-Khwārizmī", pp. 22-27. See now the edition of both, with translation and commentary, in Charette & Schmidl, "al-Khwārizmī on Instruments".

Two reasons why this would have to be a late work of his are: (1) In the treatise on the *use* of the astrolabe he is still experimenting with new definitions of the times of the *ẓuhr* and *ʿaṣr* prayers: see the commentary to Ch. 4 in App. A. (2) In his treatise on the *construction* of the astrolabe al-Khwārizmī proposes a simple linear horizontal shadow-scale, 12 units below the horizontal diameter, and in this anonymous treatise from Baghdad we are dealing with a more developed shadow-square (see App. B).

[9] Compare, for example, the Arabic in the edited texts in Charette & Schmidl, "al-Khwārizmī on Instruments".

[10] See n. 2:1 above.

[11] King & Samsó, "Islamic Astronomical Handbooks and Tables", pp. 56-59.

Marrākushī in Cairo in the late 13th century seems to have found his sine quadrant with movable cursor in an Andalusī source: see **5** and **Fig. 5a**. Furthermore, the Baghdad treatise was apparently unknown to Egyptian and Syrian astronomers of the 14th century, who were *the* specialists in different varieties of quadrants.

If the author is not al-Khwārizmī, then other possibilities are the very innovative Ḥabash al-Ḥāsib (*fl*. Baghdad, *ca*. 830-880),[12] who was particularly interested in trigonometry, or the well-known astronomer Thābit ibn Qurra (*fl*. Baghdad, *ca*. 880),[13] but I consider both unlikely.

Since the attribution is uncertain I propose not to insist on al-Khwārizmī. In any case, our author, who makes no claim to have invented the instrument, was fully in control of his subject, not least because he proposed three different equivalent forms of the instrument, and he assumed a certain basic knowledge on the part of his readers.

The markings of the universal horary quadrant described in the Baghdad treatise are in three basic forms (see **Fig. 2b)** with an optional movable or fixed calendrical/declination scale fitted in a groove on the rim (**Fig. 2c)**.[14] Alas the description of the cursor has dropped out of the text as it now stands, but from references elsewhere in the treatise it seems that the argument was the date in a solar calendar (perhaps the Persian one).[15] Essentially the markings in each of the three kinds are linked to the 15°-divisions of the outer scale, either by arcs of circles (type 1), a set of parallels (type 2), or a set of radii (type 3). Superposed on the horary markings is a shadow square with scales on each of the two non-axial sides (see **App. B**). Special markings on the curves for the 3rd and 6th hours may have been intended, in order to show their relationship to the times of prayer; these inevitably disappeared in the Latin tradition.[16]

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[12] Most of Ḥabash's treatises on instruments use 34° for the latitude of the Abbasid capital, Samarra. To add to the continuously-growing list of his writings known to us (see King, *Mecca-Centred World-Maps*, pp. 40-41 and 345-359) are the following: first, a note on the use of the alidade as a universal sundial (see further App. C), and secondly, although the attribution is not yet certain (Charette & Schmidl, "Ḥabash's Universal Plate", p. 110, n. 14), the treatise on a special sundial for latitude 34° appended to the unique 10th-century copy of Thābit's treatise on sundial theory (Morelon, *Thābit*, pp. 165-167 and 291-294, and Charette, *Mamluk Instrumentation*, pp. 205-207).

[13] Joseph Drecker (*Theorie der Sonnenuhren*, p. 86) mentions copies of Sacrobosco's treatise in the Bayerische Staatsbibliothek in Munich in which the text is associated with "Thabit" (Clm 10661) and "Albatenius" (Clm 14583). No such treatise was known to Francis Carmody who in 1960 surveyed various Arabic and Latin treatises associated with Thābit ibn Qurra (*DSB*, *s.v.*). Likewise, no such treatise was known to Régis Morelon, who in 1987 published various original Arabic texts by Thābit. "Albatenius", the early-10th-century Syrian astronomer al-Battānī (*DSB*, *s.v.*), is not known to have written on instruments other than those in the *Almagest* (the section on sundials in the unique copy of his astronomical handbook is spurious).

[14] On the Florence piece (#5503) see n. 7:1 below.

[15] On the calendars used by Muslim astronomers see King & Samsó, "Islamic Astronomical Handbooks and Tables", pp. 19-20, and the article "Ta'rīkh, iv" [= calendars] by Benno van Dalen in EI_2.

[16] In Christian Europe, all of the specifically Islamic materials in Islamic astronomical works, such as the treatment of the times of the *ẓuhr* and the *ʿaṣr* prayers, were invariably suppressed in new Latin versions. This was perhaps unfortunate in the case of the Baghdad treatise, for the procedures advocated here (see the commentary to Ch. 4 in **App. A**) would have been very useful for determining the *sexts*, as well as the *terces* and *nones*, but these were surely of less interest at the university scene in Paris than in monasteries.
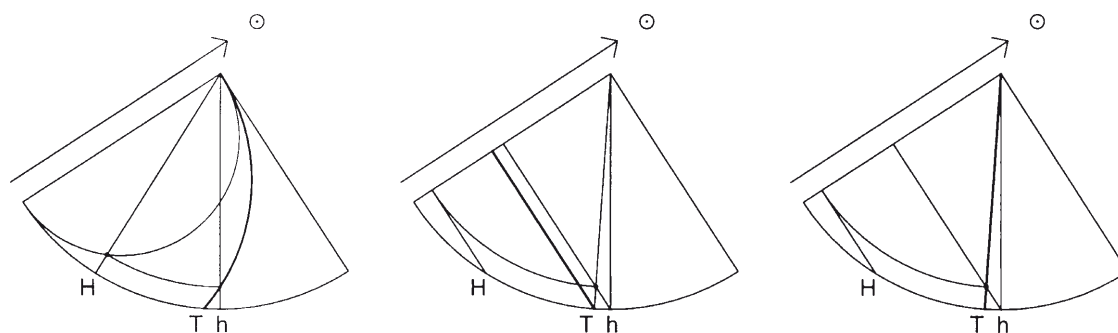
Fig. 3a: The use of the three kinds of universal quadrants to find T(h,H). Our Baghdad astronomer simply wrote: "the use of all of these is the same", and leaves the details to the imagination of his readers.

3 The approximate formula for timekeeping

The main markings serve the solution of an approximate formula for timekeeping adopted by Muslim astronomers (along with the exact formula) from Indian sources.[1] In modern notation we may render this as:

$$T = {}^{1}/_{15} \text{ arc sin } \{ \sin h / \sin H \} ,$$

where h is the instantaneous solar altitude, H is the meridian altitude, and T is the time since sunrise or before sunset in seasonal hours ($0 < T < 6$). By setting the movable bead on the radial thread in a certain way (different for each variety) to H, entered on the outer scale, and then aligning one side of the quadrant towards the sun with altitude h on the same scale, the time of day T can be read from the position relative to the hour markings of the bead on the now vertical thread (see **Fig. 3a**).

The inspiration for the formula was clearly the fact that both at latitude 0° and for all latitudes at the equinoxes it is correct. The formula is approximate for other solar longitudes and works extremely well in Mesopotamian and Mediterranean latitudes but less well in, say, Northern Europe. The errors are latitude-dependent and the maximum errors (which occur at the summer solstice)[2] for latitudes:

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[1] For derivations of an equivalent formula see already Delambre, *HAMA*, pp. 243-247; Drecker, *Theorie der Sonnenuhren*, p. 86; Lorch, "Universal Horary Quadrant"; and Archinard, "Unequal Hour Diagram", pp. 181-187. Each of these writers concentrates on the hour-angle, where as the instrument is intended for finding the time since sunrise.

The substantial literature on this formula, together with the tables and instruments based on it, is analysed in **XI**, and Charette, *Mamluk Instrumentation*, I-1.4.2-3.

[2] Compare North, "Hour-Line Ritual", p. 113. The errors using the formula are investigated more fully in **XI-2.3**.

The determination of time from solar altitude using a single universal plate known as the *shakkāziyya* in Arabic and *saphea* in Latin (see the article "Shakkāziyya" in EI_2) is also based on this formula: see Tannery, "Quadrant", p. 147, and also the discussion of the errors in Puig, *al-Šakkāziyya*, pp. 67-72. The single *shakkāziyya* quadrant also has this property (see also North, "Meteoroscope" on the same instrument used for different purposes). To solve problems involving the transformation of coordinates (and hence the exact formula for timekeeping) one needs a double *shakkāziyya* quadrant, such as was described by Jamāl al-Dīn al-Māridīnī *ca*. 1400: see King, "The *Shakkāzīya* Quadrant of al-Māridīnī".

	30°	40°	50°	
are of the order:				
	6	9	14	seasonal minutes,
that is,	7	11	19	equinoctial minutes.

The virtue of the formula is not only its simplicity but also its universality and efficacy (at least within the regions in which it was first conceived). One could add that for most times of day during most of the year in places with latitude less than, say, 40°, the formula works extremely well.

The construction of the markings of type 3 is trivial, for type 2 less so, and for type 1 simple when one has found the centres of the circular arcs.[3] The operations with the markings of type 3 are facilitated by having also a set of horizontal parallels.

4 The optional cursor

The addition of a movable cursor attached in a groove on the outer scale enables the user to enter H throughout the year knowing only the local latitude ϕ and the solar longitude λ or the date if a calendar scale is present: it is not essential to the basic operation of the instrument. The scale on the cursor essentially serves to show the solar declination δ as a function of λ,[1] so that if the centre of the cursor is set at argument $90° - \phi$, which is the solar equinoctial meridian altitude, the mark for λ on the cursor will be at argument $90° - \phi + \delta$, which is H, on the outer scale. It was not too much to expect that the medieval astronomer or user in general might know the solar meridian altitude on a given day: this function was tabulated in medieval ephemerides,[2] and medieval tables displaying time of day as a function of solar altitude sometimes had the solar meridian altitude as the other argument (otherwise it would be the solar longitude).[3]

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[3] See the discussions in Lorch, "Universal Horary Quadrant", pp. 116-117; **XI-2.2**; and Charette, *Mamluk Instrumentation*, pp. 211-215.

[1] A scale for, say, each degree of δ is trivial to construct; a scale based the solar longitude λ is more complicated, but still simple using an analemma construction. A scale based on the months requires a table showing the dates of the sun's entries into the signs—see **XIIb-9d**. A good description of such scales is in Fantoni, *Orologi solari*, pp. 351-357.

Similar scales for converting λ to δ or sin δ or tan δ are found on other early medieval instruments. An example for δ is found on a universal instrument for timekeeping by the stars by Habash al-Hāsib, a contemporary of al-Khwārizmī (see Charette & Schmidl, "Habash's Universal Plate", p. 154). An example with which one could find sin δ and cos δ is on the universal horary dial on the sole surviving *albion* in the Osservatorio Astronomico, Rome (illustrated in North, *Richard of Wallingford*, III, pl. XXIII). The declination scale on the bottom of the universal horary dial on the medieval English *navicula*s serves to determine δ and that at the side tan δ. See further **XIIb-7**.

[2] As, for example, in the 14th-century tables for the Yemen and Oxford—see the article "Taḳwīm" [= ephemeris] by Michael Hofelich in EI_2, and Nicholas of Lynn, *Kalendarium*, respectively. In the tables of solar altitude for the equinoctial hours at the latitude of Baez compiled *ca*. 1435 by pseudo-Enrique de Villena (*Astrología*, pp. 171-176), one argument is the dates for which the solar meridian altitude can be rounded to a given degree.

[3] See **I-2**.
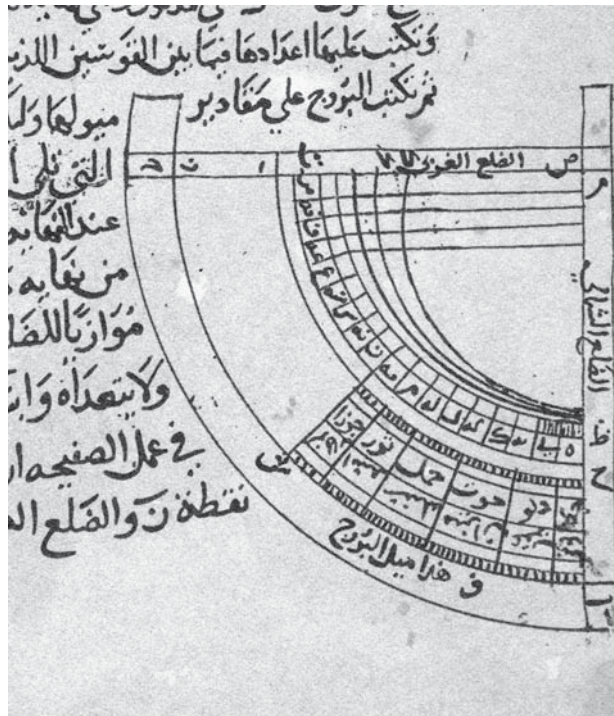
Fig. 5a: A diagram of a universal horary quadrant (type 2 with additional orthogonal meridians—see **Fig. 2b**) with movable cursor found in the treatise on instruments for timekeeping by al-Marrākushī. This appears to be a development from the markings of the back of the *zarqālliyya* plate, but al-Marrākushī refers to this, the back of a *zarqāllī* quadrant, as a sine quadrant. [From al-Marrākushī, *A-Z of Astronomical Timekeeping*, I, p. 376, from MS Istanbul Topkapı Ahmet III 3343, copied in 747 H [= 1346/47].]

The provision of a fixed cursor immediately limits the universal application of the cursor itself, but not the potential universal application of the horary markings. A solar scale anywhere other than on the outer rim of the quadrant, such as on the radii of the quadrant or on a radial rule, would also compromise the spirit of the markings, because the scale itself is necessarily latitude-dependent.

5 The *"quadrans vetus"* in the Islamic world

The universal horary quadrant with a movable cursor apparently had little success in the Islamic world. The answer to the inevitable question "Why?" is quite simple: better instruments, and also extensive tables, were available to the Muslim astronomers for timekeeping. This did not stop Rabbi Çag in Toledo in 1276 from compiling a treatise on the construction and use of the *quadrans vetus* (here called "*el quadrante con que rectifican*"): this appeared in Middle Castillian in the *Libros del saber de astronomía*.[1] Furthermore, Abū ʿAlī al-Marrākushī (*ca.*

[1] Rico y Sinobas, ed., *Libros del saber*, V, pp. 285-316, discussed in Millás, "Cuadrante con cursor", pp. 66-67, *etc*.

1280) described and illustrated such a quadrant with markings of type 2 (**Fig. 5a)**, which he surely took from Andalusī sources.[2] I know of no other texts dealing with such quadrants with movable cursors. Furthermore, no Islamic examples of such quadrants with any such cursors are known to have survived. To the other inevitable question: "How could such an important treatise survive only in a very late copy?", I can only refer the reader to other examples of such situations.[3]

6 On some other Islamic varieties of quadrants

The straight lines of types 2 and 3 lend themselves at first sight more readily to further applications in spherical astronomy than those of type 1. However, it was not beyond the wit of certain Muslim astronomers in the 14th century to find general applications of even the markings of type 1. They conceived sophisticated instruments based on various modifications of the basic markings (**Figs. 6a-b**), but these were not widely used outside the circles of Mamluk and Ottoman specialists in timekeeping.[1]

It should be noted that there is another type of markings which we find very occasionally on Islamic trigonometric grids. I label them "orthogonal meridians" (see **Fig. XIIb-16a**), with the understanding that they are not to be confused with markings for the hours. These consist of a set of quarter ellipses, resulting, like the parallel horizontal lines, from an orthogonal projection. However, a clever trick avoids the crowding of the markings near the limits: the ellipse segments are drawn for a set of uniform divisions on the horizontal radius, and there is a non-uniform scale on the radial rule corresponding to the Sines of the corresponding arguments. These markings appear in al-Andalus in the 11th century on the plate of an otherwise standard astrolabe,[2] and on the back of the universal plate of Ibn al-Zarqālluh.[3] The Eastern Islamic origin of such markings has already been suspected.[4] The combination is also attested on the (Andalusī?) "*quadrans vetus*" illustrated by al-Marrākushī (see **Fig. 5a)**.[5]

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[2] On al-Marrākushī see n. 2:6. It seems that his information on this and other horary quadrants came from al-Andalus rather than from Baghdad. See also Viladrich, "Horary Quadrant", pp. 285-286 (on MS Cairo ṬM 155,3, *copied ca*. 1700, of a quadrant treatise *compiled ca*. 1150).

[3] King, *Mecca-Centred World-Maps*, pp. 366-367. The treatise on the universal horary quadrant is one of these examples, but Iranians in Meshed *ca*. 1800, almost a thousand years after the Baghdad treatise was first penned, did not start producing *quadrantes vetera* because they had no need for such instruments. See, however, n. 14:4.

[1] See, for example, the illustrations in King, "Astronomy of the Mamluks", p. 546, and *idem*, *Studies*, B-IX, p. 8, and more especially Charette, "Der geflügelte Quadrant".

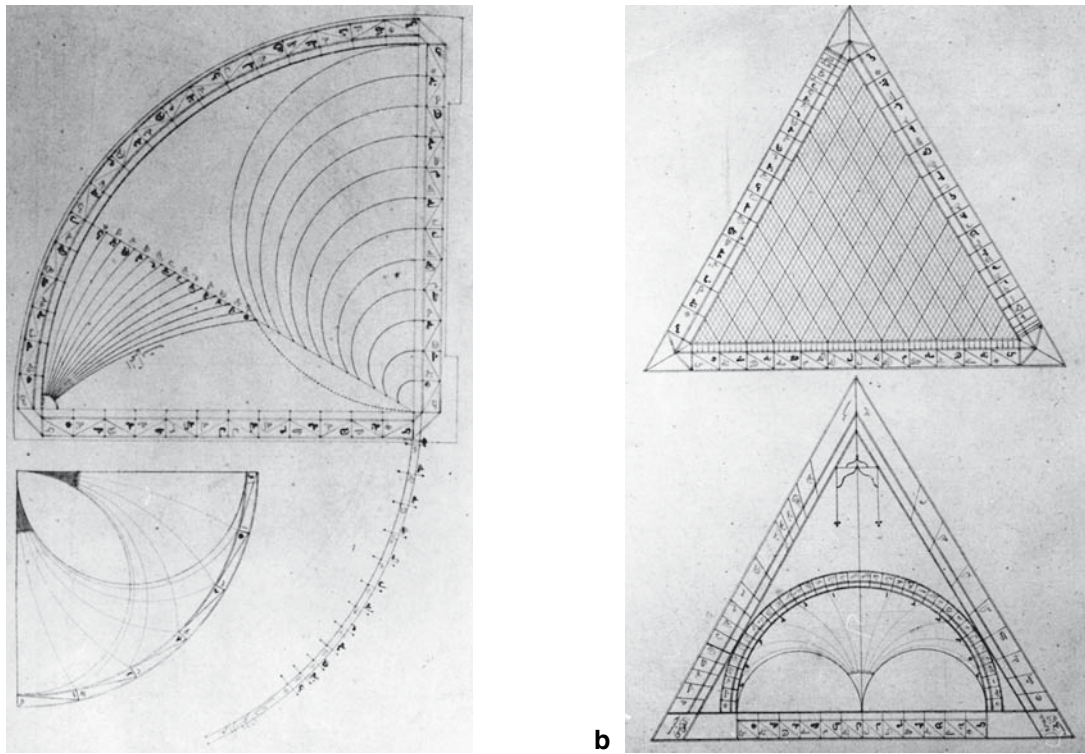
[2] #123, signed by Ibrāhīm ibn Saʿīd al-Sahlī, dated Valencia, 463 H [= 1070/71]—Osservatorio di Roma—unpublished.

[3] Illustrated in Puig, *al-Šakkāziyya*, p. 201.

[4] See Puig, "Ibn al-Zarqālluh's Orthographic Projection". The origins of this grid are thus in astronomical timekeeping rather than cartography. Other examples of instruments on which mathematically-inspired grids have been confused with projections come to mind: see, for example, the grids on the maps described in King, *Mecca-Centred World-Maps*, and also **XIIb-15-16**.

[5] In fact, the combination is attested elsewhere in Islamic and Latin instrumentation and cartography and

a

b

Figs. 6a-b: Illustrations of three instruments for timekeeping from 14th-century Syria, invented by Ibn al-Sarrāj and a fourth (upper left) by Ibn al-Shāṭir. The illustrations are in the hand of Muṣṭafā Ṣidqī (see n. 11:1 to **XIIb**). [From MS Cairo MR 40,2, courtesy of the Egyptian National Library.]

In addition, a family of quarter-circles, which likewise cannot be used to represent the hours, can be useful. Markings of this type appear already on sine quadrants from 10th-century Baghdad (see **Fig. 10a**).

Muslim astronomers also developed different types of sine quadrants from the simple markings of types 2 and, to a lesser extent, type 3, sometimes combining these with "orthogonal meridians", and, less frequently, a set of concentric quarter-circles. Some of these were widely used until the 19th century,[6] although the most developed form, with equally spaced horizontals and verticals (like modern graph paper), and now serving the solution of any problem of spherical astronomy, predominated at least from the 14th century onwards.[7] Thus, for example,

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merits a separate study. See already King, *Mecca-Centred World-Maps*, pp. 34-37, esp. fig. 1.7.5 and nn. 68-69.

[6] The best account is still Schmalzl, *Geschichte des Quadranten*, pp. 71-99. Two recent publications on treatises on early versions of this instrument are Charette & Schmidl, "al-Khwārizmī on Instruments", pp. 154-155 and 179-181, and Lorch, "Sine Quadrant".

[7] This was a common feature on both medieval and late Islamic quadrants and also on the less-common medieval European *sexagenarium* (see Poulle, "Sexagenarium"). It is first discussed and illustrated in a treatise on an astrolabe with astronomical tables engraved on it as well as an equatorium by the 10th-century astronomer Abū Jaʿfar al-Khāzin (extant in an unpublished manuscript preserved in Srinagar, Kashmir—see King, *Mecca-Centred World-Maps*, p. 369, n. 11).
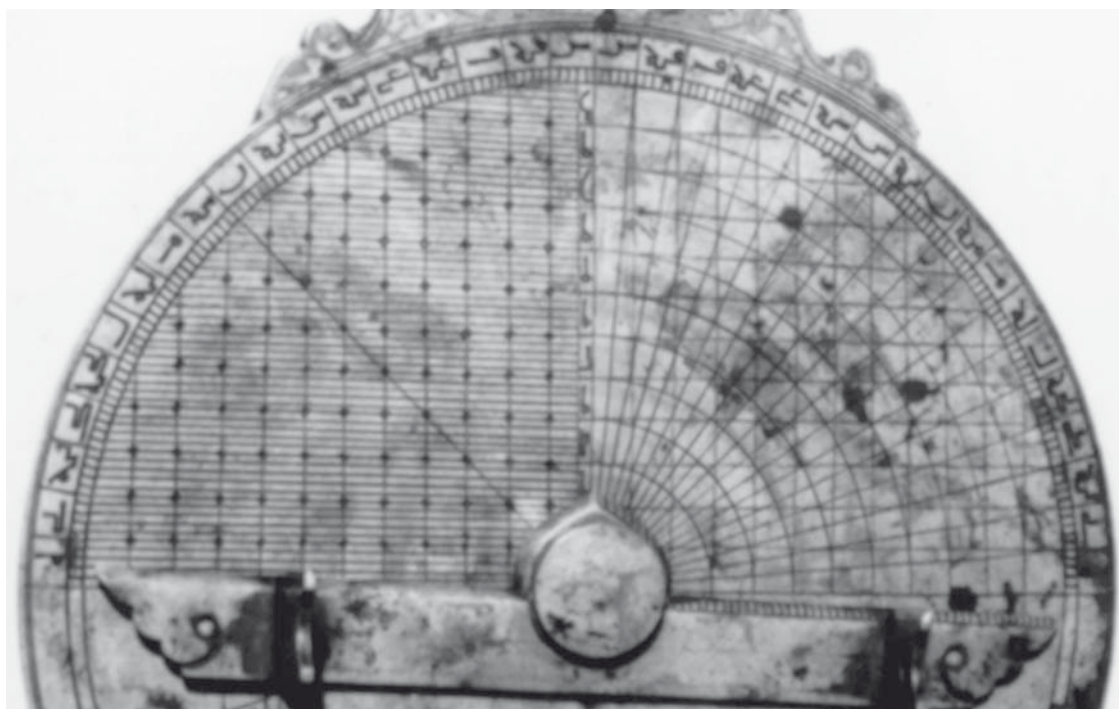
Fig. 6c: The trigonometric markings on the back of the astrolabe made by Mukhliṣ Shirwānī in 910 H [= 1504/05] (#12). [Courtesy of the Museum of Islamic Art, Cairo.]

on the back of the astrolabe (#12) made by Mukhliṣ Shirwānī in 910 H [= 1504/05] for the Ottoman Sultan Bāyazīd II (see **Fig. 6c**), we find in addition to a sexagesimal sine quadrant on the upper left a quadrant of markings on the upper right with a combination of equi-spaced horizontal parallels for each 5 units (type 2), radii for each 5° (type 3), and quarter-circles for each 5 units. If one had asked the maker why he did not put a universal horary quadrant on the back he might well have answered that it was completely superfluous since (for the latitudes he cared about) one could do everything properly with the front of the astrolabe (illustrated in **Fig. XIVe-1.1**).

7 The *quadrans vetus* in Europe

The *quadrans vetus* of medieval European astronomy consists of a set of universal horary markings with a movable cursor and a shadow square. Remarkably few examples survive, given the substantial medieval Latin textual tradition. Each of three surviving medieval examples appears to be French. They are preserved in Florence (complete), Oxford (cursor broken), and London — see **Figs. 2c** and **X-6.2.1** for the first two.[1] Another preserved in Vienna is probably

[1] #5502—Oxford, Museum of the History of Science, inv. no. 52020—illustrated in Poulle, *Instruments*

from the German-speaking world—see **Fig. XI-10.2a-b**.[2] The instrument is nothing more nor less than the Baghdad quadrant of type 1. Even in the Renaissance the *quadrans vetus* was still being made: see **Fig. 7a** for a 16th-century German example.

The so-called *quadrans vetustissimus*, a modern appellation for another variety of quadrant illustrated in the medieval European sources,[3] is the Baghdad quadrant of type 2, with parallels drawn for more than each 15°. Several modern authors have devoted much time and energy to establishing the inter-relationship between the various Latin texts on the *quadrans vetus*;[4] a task for the future will be to investigate their relationship to the Baghdad treatise, which perhaps involved an Andalusī text as intermediary.[5]

A universal horary quadrant appears with a fixed declination cursor on the back of a 14th- (or possibly 15th-)century *navicula* preserved in Florence: the underlying latitude is 52°, which would normally suggest England, but the design is more in the German tradition: see **Fig. XIIb-2c**.[6] The universal horary quadrant was also used in Europe without any cursor. Two rather spectacular examples larger than standard astrolabes are preserved from 14th-century England: see **Fig. 7b** for one of these.[7] Several smaller examples are known; for one of Italian provenance see **Fig. 7c**.

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astronomiques, 1969 edn., p. 19; see now Meliconi, "Oxford *Quadrans vetus*" on EPACT.

#5503—Florence, Museo di Storia della Scienza, inv. no. 662—illustrated in Poulle, *Instruments astronomiques*, 1983 edn., p. 10, and King, *Mecca-Centred World-Maps*, p. 356; see now A. J. Turner, "Florence *Quadrans vetus*" on EPACT.

#5504—London, British Museum, inv. no. 1972 1-4 1—see *London BM Catalogue*, p. 55 (no. 145) and pl. XX, and now Ackermann, "London BM *Quadrans vetus*" on EPACT.

Meliconi, Turner and Ackermann have the provenance of these three pieces as "*ca*. 1300, French?", "14th century, German", and "14th century, English". Already Turner points out that the engraving on the three pieces is distinct, but the Oxford and London pieces shows a closer resemblance to each other than to the Florence piece. It is, of course, idle, to speculate about the provenance of such pieces without comparing them with contemporaneous instruments whose provenance is established. However, the Florence piece is not German.

[2] #5505—Vienna, Kunsthistorisches Museum, inv. no. ?—unpublished. This has been regarded as a fake, but it is a serious instrument.

[3] See Millás "Cuadrante con cursor", who introduces the term to distinguish the instrument from the *quadrans vetus*, which he thought it must precede; Zinner, "Invento español"; and also Lorch, "Universal Horary Quadrant", p. 118. The instrument described in the Hebrew text of Mordecai Comtino (Constantinople, 15th century)—see Goldstein, "Astronomical Instruments in Hebrew", p. 123—is not a *quadrans vetustissumus* but rather a latitude-specific horary quadrant (see also nn. 13:2-3 for Derek Price's dismissal of the 14th-century English examples as fakes, quoted by Goldstein).

[4] See, most recently, Knorr, "Sacrobosco's *Quadrans*", and "*Quadrans Vetus*", especially p. 23 (extensive bibliographical references). On p. 213 of the first paper, Knorr summarised previous research on the dating of the *quadrans vetus*.

[5] On the omission of the material relating to Islamic prayer-times see n. 2:16. By the 10th century the Andalusīs were using different definitions for the times of the midday and mid-afternoon prayer from those used in the Baghdad treatise.

[6] #8532—Florence, Museo di Storia della Scienza, inv. no. 3163—see **XIIb-10**.

[7] #296—Oxford, Oriel College—see Gunther, *Astrolabes*, II, p. 473 (no. 296). Of particular interest is the highly ingenious (and unique) combination of the altitude scale and shadow scale in the form of a crescent below the horary markings: see **App. B** and n. B:12.

Fig. 7a: A *quadrans vetus* from Germany dated 1523 (#5515). The traditional medieval markings have been supplemented by a set of horary markings for the equinoctial hours together with a latitude-dependent radial solar-scale and an additional fixed circumferential solar scale, by the side of which is an inscription indicating that the ensemble serves the 8th climate, whose latitude is unhappily taken as 54°. [Present location unknown; photo courtesy of Auktionshaus Hampel, Munich.]

Fig. 7c: An Italian universal horary quadrant (#5501) made of wood with an unconvincing solar scale on the left-hand radius. [Present location unknown; photo courtesy of the former owner, Dr. Tullio Tomba, Milan.]

8 The *quadrans novus*

We should also mention the *quadrans novus*, an instrument apparently first described by Yaʿqōb ben Makhīr, also known by the names Ben Tibbōn and Profatius, in Montpellier *ca*. 1290, which enjoyed some popularity also mainly in medieval France.[1] This is simply a *quadrans vetus*, inevitably with a shadow square, now fitted with a stereographic projection of the ecliptic, a few stars and various horizons on the front (**Fig. 8a)**, and sometimes with a sexagesimal sine quadrant on the back, though more usually, calendrical-solar scales. This is something of an unfortunate instrument in that for approximate timekeeping one uses the *quadrans vetus*, for problems relating to horizon phenomena—such as determining the length of daylight and the lengths of the seasonal hours—one can use the horizons, but—since there are no altitude circles—for serious timekeeping by day or by night one must, each time, solve the accurate formula from scratch using the trigonometric grid.[2] On some instruments this is replaced with a calendrical scales.

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[1] Anthiaume & Sottas, "*Quadrans novus*"; Poulle, "*Quadrans novus*"; and Dekker, "*Quadrans novus*". On Profatius see the article "Ibn Tibbon, Jacob ben Machir" by Juan Vernet in *DSB*.

[2] This is a real pain. A. J. Turner (*Rockford TM Catalogue*, p. 203), wrote: "The obvious practical
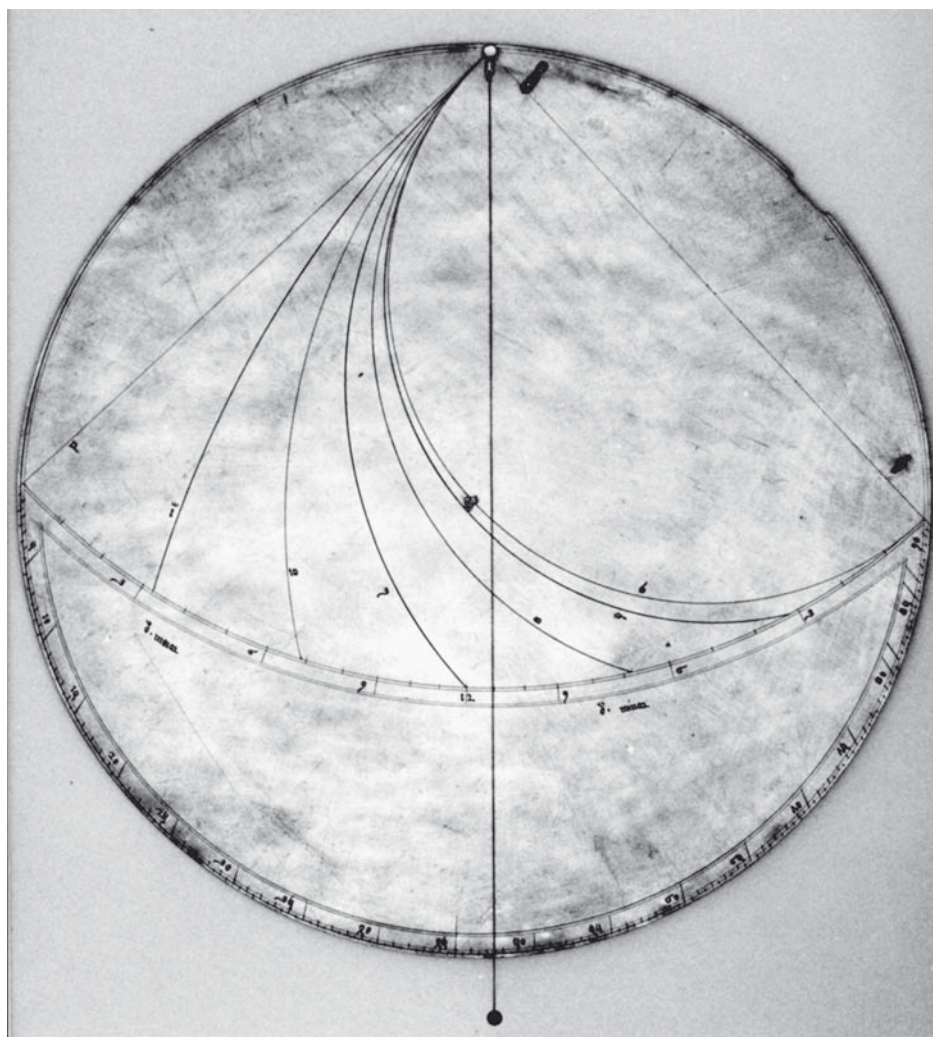
Fig. 7b: The universal horary quadrant on the back of a 14th-century English astrolabe (#296). On the shadow scales see further **App. B**. [Courtesy of the Museum of History of Science, Oxford.]

The surviving medieval *quadrantes novi* are nine in number and several have been studied.[3]

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disadvantages of this in everyday life sufficiently account for its disappearance." Elly Dekker ("*Quadrans novus*", p. 6) observed that: " ... it is rather complicated, although not impossible, to use the *quadrans novus* when a more precise determination of time is demanded than that obtainable with the "universal" hour lines of the *quadrans vetus*." Dekker goes on to laud the "combination of various elements leading to a completely new multipurpose instrument" with which "all sorts of problems in spherical astronomy and astrology can be solved". (Poulle, "*Quadrans novus*", p. 203, had listed 28 such problems.) But without a convenient means of deriving the time accurately, the instrument is fundamentally flawed. No previous authors have addressed the combination and superposing of approximate and accurate markings on a single instrument.

[3] The reader should be aware that the new study of Elly Dekker, which I label "*Quadrans novus*", is a detailed description of one piece (#5509 below), with comparative materials drawn from the other instruments. Whilst

The main markings of the *quadrans novus* sit unhappily on the back of a medieval English astrolabe,[4] for they contribute nothing that is not already on the front of the astrolabe, except, of course, the universal horary markings. A German translation of the *quadrans novus* text was prepared in the mid 15th century, and several later (Renaissance) instruments of German and also Italian provenance survive.[5]

The *quadrans novus*, a universal instrument, has been confused in the modern literature with the astrolabic quadrant, a latitude-specific instrument of different provenance and with a different function.[6] The astrolabic quadrant, a simplified version of the astrolabe for a specific latitude, was an Islamic invention that was already well known in Egypt in the 12th century (see **11**). I myself have claimed that the *quadrans novus* was unknown in the Islamic world (before and after Profatius):[7] now I would prefer to be quoted as claiming that although all of the components were known in 9th- or 10th-century Baghdad, it seems to have been Profatius who combined them in a way which was not known in the Islamic world. In fact, the astrolabic quadrant was known in medieval Europe after all: all the elements of the front of the *quadrans novus*, and a few more, including a universal horary dial, occur separately on a Renaissance European instrument in the medieval tradition (English with German influence?) preserved in Oxford (#8501).[8] On this piece, signed by Roger Brechte in 1527, the ecliptic markings are

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some of these are still "unpublished", considerable information of them can be picked up from Dekker's tables of star-names, calendrical information, *etc*. The extant pieces are:

#5506 = #2110—undated—Oxford, Merton College—see Gunther, *Science in Oxford*, II, pp. 164-169; North, *Richard of Wallingford*, III, p. 134; and Dekker, "*Quadrans novus*", p. 20, *etc*.

#5507—undated—Washington, National Museum of American History, inv. no. 326975—see Dekker, "*Quadrans novus*", pp. 16-17, *etc*.

#5508—undated—present location unknown—described by D. A. King and Elly Dekker in *Christie's London 02.03.1995 Catalogue*, p. 35 (lot 198).

#5509—undated—private collection—published in detail in Dekker, "*Quadrans novus*".

#5511—undated, French—Rouen, Musée des Antiquités de la Seine Maritime, inv. no. 919—published in Anthiaume & Sottas, "*Quadrans novus*"; see also Dekker, "*Quadrans novus*", pp. 18-19, *etc*.

#5512 = #2111—undated, datable to 1415, French—Angers, Musée de Saint-Jean, inv. no. MA GF39—unpublished, see Dekker, "*Quadrans novus*", p. 22, *etc*.

#5514—undated—Lüneburg, Museum für das Fürstentum Lüneburg, inv. 122—see Dekker, "*Quadrans novus*", p. 21, *etc*.

[4] #5513 = #2006—undated, English—Washington, D.C., National Museum of American History, inv. no. 318198—see *Washington NMAH Catalogue*, figs. 16 (p. 14), 20 (p. 23), and 28 (p. 46), and pp. 45-47 and 153-154 (no. 2006).

[5] A list is in Dekker, "*Quadrans novus*", p. 6, n. 8.

[6] The process apparently began in 1957, when Francis Maddison (*Oxford MHS Billmeir Supplement Catalogue*, p. 45) wrote: "The typical Islamic quadrant is engraved on one side as a (trigonometric quadrant), and on the other as a Prophatius astrolabe-quadrant". This was repeated over several decades in catalogues of Christie's and Sotheby's. In the *Rockford TM Catalogue*, 1:1, pp. 202-206, the error is repeated by Anthony Turner, but now with a diagram confusing the two different sets of markings still further: fig. 167 on p. 203 shows altitude circles on a "Prophatius quadrant". Perhaps the remarks in King, "Cataloguing Islamic Instruments", col. 255, will put an end to this confusion.

[7] King, *"Astronomical Instruments between East and West*", p. 165.

[8] #8501—Museum of the History of Science, Oxford (formerly St. John's College, Oxford), inv. no. 26323—see Gunther, *Early Science in Oxford*, II, pp. 135-140 (no. 56), and **XIIb-11**. This very medieval-looking instrument bears the name Roger Brechte and the date 1537, both contemporaneous with the other markings on the piece.

Fig. 8a: A *quadrans novus* from the 14th century (#5506). The northern and southern branches of the astrolabic ecliptic scale meet at the vertical radius, the branches of the astrolabic horizons (for four latitudes) meet at the horizontal radius. The latitudes are *ca*. 44°, 52°, 54°, and 66½°, the first probably for Montpellier, a gentle reminder of the inventor Profatius, and the last serving celestial coordinate conversion. The middle two confirm that this is an instrument made for use in England. [From G. Turner, ed., *Strumenti*, p. 71; object in Merton College, Oxford.]

combined with altitude circles for each 15° for a latitude of *ca*. 50° (see further **XIIb-11**). So at least one medieval European astronomer preferred not to combine the traditional markings of a *quadrans novus*. The inspiration for his instrument remains a mystery.

I have previously argued that the representation of the entire ecliptic as two arcs within a quadrant, such as is found on the *quadrans novus* of Profatius *ca*. 1290 and also as item (3) on the Brechte plate, is a European innovation. But it appeared on the astrolabic quadrant already in 12th-century Egypt,[9] and furthermore the astrolabe with a crescent-shaped ecliptic (of which the markings on these quadrants constitutes one-half) was described by al-Sijzī in the late 10th century, and hence also by the major Muslim specialists on instruments, such as al-Bīrūnī, al-Marrākushī and Najm al-Dīn al-Miṣrī.[10]

[9] See n. 11:1 below.
[10] Charette, *Mamluk Instrumentation*, II-2.3.3-4.

A medieval Hebrew text has been identified describing an instrument that is an intermediary between the astrolabe and the *quadrans novus*. On the front of an astrolabic plate we find here the stereographic projections of the three base circles, the ecliptic and some stars, as well as *a series of horizons for different latitudes*.[11] The same instrument *without the horizons* was actually made in 733 H [= 1332/33] by Ibn al-Shāṭir, chief astronomer at the Umayyad Mosque in Damascus, who said he invented it.[12]

9 Universal horary markings on astrolabes and their use

These horary markings were added to the back of the astrolabe to afford a quick means for finding the time of day for any latitude: if one wants to do this accurately one should use the appropriate plate on the front of the instrument (to find the time in equinoctial or seasonal hours), or construct an horary quadrant for a specific latitude (for one or other kind of hours).[1] If a universal horary quadrant was not included on a serious astrolabe, it might well be that the engraver preferred an alternative, which would often reflect a regional interest (other varieties of trigonometric quadrant, latitude-specific horary quadrants, a universal stereographic projection, solar and calendrical scales, lists of saints' days, astrological scales, graphs showing the solar altitude in the qibla of different cities throughout the year, *etc*.). The universal horary quadrant had little priority on astrolabes because it served only as an alternative additional means of rendering the instrument universal.[2]

A uniform sexagesimal scale on the alidade of the astrolabe could replace the thread and bead of the quadrant, but since there is no need to measure anything on the scale, a plain alidade could suffice, with a small blob of some adhesive substance to mark the equivalent of the bead on the thread. Whereas in Arabic treatises on instruments authors tended to write simply *ʿallim ʿalāma*, "make a mark", European authors, if not already some Muslim authors, were more specific when describing the operation of the universal horary quadrant on the back of an astrolabe, proposing marks with ink or wax.

This tradition seems to be first attested in the treatise on the use of the astrolabe by Philoponos.[2a] When describing the way to measure the altitude of the sun with the alidade, he writes (Gunther's version):

> " ... it is necessary to mark with ink or something of the sort the line on which the index of the rule fell and to measure how great it is ... ".

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[11] Goldstein, "Astronomical Instruments in Hebrew", pp. 121-123.

[12] On Ibn al-Shāṭir see the article in *DSB*. On this instrument of his (#142—Paris, Bibliothèque nationale de France, Département des cartes et plans; and #1131—Cairo, Museum of Islamic Art) see *ibid*., p. 361b, and Mayer, *Islamic Astrolabists*, pp. 40-41. The unusual markings on the back are illustrated in King, "Mamluk Universal Solutions", p. 165, and **Fig. VIb-8.2** (inappropriately described as a "trigonometric grid").

[1] On several latitude-specific horary quadrants—instruments and descriptions in texts—see the preliminary study of Mercè Viladrich mentioned in n. 1:11, and the more detailed information in Charette, *Mamluk Instrumentation*, pp. 116-139.

[2] On the "universality" of the astrolabe see n. 1:6.

[2a] Gunther, *Astrolabes of the World*, I, p. 67.

Then, to mark the position of the sun on the ecliptic scale on the rete, he writes:

> "It is necessary then to mark with ink or wax, or something of the sort, the twentieth degree of Aris upon the zodiac of the Arachne ... ",

and to mark the altitude circle on the plate:

> "then it is necessary to mark this circle with ink with numerous dots along nearly all the line. ... "

He advocates such markings elsewhere in his treatise, and one might even expect him to instruct the user to clean the astrolabe once he has finished using it.

Thus, for example, in the popular Latin astrolabe treatise attributed to Messahalla—but actually based on the Arabic of Maslama al-Majrīṭī (*ca*. 1000)—we read (Gunther's translation):[3]

> *Super altitudinem solis meridianam in illa die pone allidadam; et nota ubi meridianus circulus, id est, linea finis .6. hore, secuerit lineam fiducie ipsius allidade; et pone ibi signum de incausto; et illud signum valet situationem margaritae in quadrante; deinde accipe altitudinem solis in quacunque hora vis, et illud signum inter horas dabit horam naturalem, ut in quadrante.* // Set the alidade to the meridian altitude of the sun on the day; and note where the meridian circle, i.e. the sixth hour line, cuts the line of trust (leg: fiducial edge) of the alidade; place thereon a mark of ink; and that mark will be the place of the bead on the quadrant. Then take the sun's altitude at any hour you please, and the mark between the hours will give the natural (i.e. seasonal) hour, as on a quadrant.

Gunther notes that according to the Italian translation (date?) one should mark "*un segno non apparente*". Likewise, Jean Fusoris, writing in Paris *ca*. 1400, advocated the following:[4]

> *... mectez l'alidade sur la haulteur de midi et puis signez d'encre, de cire ou autrement le lieu ou ladicte alidade trenche le cercle de midi ... ... et adoncques le signe d'encre dessusdit vous monstrera les heures inesgalles ...* // ... place the alidade on the midday altitude and then mark in ink or wax or otherwise the place where the alidade crosses the midday circle. ... ... Then the ink mark will show you the unequal hours ... .

Again, Johannes Stöffler, in the early 16th century, wrote:[5]

> *... illic fac notam cum cera aut atramento, aut cum cursore, si alhidada eundem haberet*. // ... make a mark there with wax or ink, or with the cursor, if the alidade has one.

Stöffler adds that the marker will serve for 2 or 3 days before it needs to be moved or remade. An English astrolabe treatise partly based on Stöffler, *The Travailer's Ioy and Felicitie* by Robert Tanner, "Gent. practitioner in Astrologie & Phisick", published in London in 1587, says the same:[6]

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[3] Gunther, *Science in Oxford*, V, pp. 221 and 174.

[4] Poulle, *Fusoris*, p. 116.

[5] Ioannis Stoflerinus, *Elucidatio fabricae vsvsqve astrolabii*, Oppenheim, 1524, p. 28r. This reference was kindly provided by Reinhard Glasemann of Frankfurt in my instrument seminar *ca*. 1982.

[6] From the facsimile in Gunther, *Astrolabes*, II, p. 511 (facsimile of fols. 13v-14r of the original).

By thys manner you shall finde out the unequall howres, in the backe of the Astrolab. The little bowes of the howres unequall, are framed in the backe, over the Lather [i.e. ladder] of measure of height. Therefore learne the Meridian height of the Sunne, to the day propounded, which being founde, in the touching of the lyne of the 6. howre sette a marke on the Index, and you shall keepe thys marke two or three daies if you please, because in that while, it will not be greatly altered. Last of all, the sun shyning, take the height of it before or after noone, and the mark of y(ou)r Index spoken of, the same height standing still, doth shewe the unequall howre to thee, concerning the dominion of the Planets in unequall howres. I let it passe, because the matter is commonly known every where.

In most modern accounts of the astrolabe these subtleties are overlooked,[7] which accounts for part of the confusion now associated with the use and the scope of the markings. On the astrological associations of the seasonal hours see further **13**.

10 Universal horary quadrants on Islamic astrolabes

Universal horary markings alone, usually in type 1,[1] less frequently in type 2, and very occasionally in type 3,[2] were very occasionally added to the backs of Islamic astrolabes from the 10th century onwards, if not already in the 9th. (From now on, we shall concentrate on those of type 1: the development of the others belongs more to the history of the sine quadrant.[3]) Thus an astrolabe made in Baghdad in the year 343 Hijra [= 954/55] (#100) bears a universal horary quadrant in the lower right, appropriately labelled *āfāqiyya*, "universal"; an horary quadrant for Baghdad in the upper left, labelled *li-ʿarḍ lām-jīm*, "for latitude 33°"; and a sine quadrant with markings of type 3 supplemented by a set of quarter-circles (**Fig. 10a**).[4] Universal horary markings feature on various Islamic instruments until *ca*. 1900, but one can be more specific.

On early Eastern Islamic astrolabes universal horary markings are rare. On early Western Islamic astrolabes (to 1100) they do not occur. We find them on some later Andalusi, Maghribi, Mamluk and Iranian astrolabes. When they occur on Islamic astrolabes, it is usually in

[7] One exception is García Franco, *Astrolabios en España*, pp. 218-221, esp. p. 219, where the application of ink to mark the meridian position on the alidade is mentioned. The procedure is also correctly outlined in Saunders, *All the Astrolabes*, pp. 22-23, where it is stated that the intersection of the alidade with the midday curve is to be "noted on the graduations of the alidade scale", which graduations are "of no intrinsic significance", serving only to "identify (the required) point". If, of course, there are no graduations, one has to mark the point some other way.

[1] One could argue that the markings of type 1 were favoured because they might have been considered more aesthetically pleasing than the other two types; another reason they were favoured was surely the fact that they are visually closer to a set of horary markings for a specific latitude than any family of straight lines.

[2] An astrolabe (#4054) by al-Khamāʾirī of Seville dated 619 H [= 1223/24] has markings of types 2 and 3 combined for each 15°. See *Linton Collection Catalogue*, pp. 171-173 (no. 221), and also n. 15:2 below.

[3] This is in dire need of being rewritten. See n. 6:6.

[4] #100—stolen from the Museo Nazionale in Palermo some 50 years ago—published in Mortillaro, "Astrolabio arabo"; see also King, *Mecca-Centred World-Maps*, p. 356, and now **XIIIc-8.1**.

Fig. 11a: Universal horary markings included on a standard Islamic astrolabic quadrant from the Maghrib datable *ca*. 1500, here serving latitude 34°, that is, Meknes (#5027). [Photo courtesy of Christie's, London.

Fig. 10a: The back of an astrolabe made by Ḥāmid ibn ʿAlī al-Wāsiṭī in 343 Hijra [= 954/55] (#100). The horary quadrant in the upper left serves latitude 33°, that is, Baghdad. Note that the scales on the shadow square together with the universal horary markings have not been completed: they are partly rendered superfluous by the shadow scale on the lower right rim. The alidade is unfortunately missing, but so is the instrument. [From Mortillaro, "Astrolabio arabo".]

conjunction with some other variety of trigonometric quadrant. On some late Islamic instruments (including not a few fakes and decorative pieces), all constructed long after the underlying mathematics had been forgotten, there was a tendency to render the horary markings incorrectly by inversion, rotation or some other distortion. See **Fig. XI-11.3e-f**.

11 Universal horary quadrants on Islamic astrolabic quadrants

Universal horary curves are mentioned, along with various other additional scales and markings, in the earliest known treatise on the astrolabic quadrant for a specific latitude, compiled in Cairo in the early 12th century: see **Fig. X-6.4.4**.[1] Whilst they are only occasionally

[1] Extant in MS Istanbul (Süleymaniye) Haci Mahmud Efendi 5713, fols. 10v-25v, esp. fols. 12r-v. The date of copying of this manuscript (fol. 34v) is only partially legible: it reads Wednesday, Ramaḍān 1, 5?? Hijra, which might be 530 H [= 1135/36], although one would never derive this from the Arabic (*sanat l-ʿ-h* or

found on 14th-century Mamluk astrolabic quadrants in a minuscule form added near the centre of the main latitude-specific markings, they became a common feature in this form on Ottoman instruments of this kind up to 1900. See **Fig. 11a** for a 15th-century example from Tunis.[2] On some astrolabic quadrants the markings are even smaller relative to the main astrolabic markings. It is clear that they then become too small for sensible use, but their theoretical purpose remains unchallenged: to provide a quick solution for all latitudes to supplement the exact solution provided for a specific latitude by the main markings.

12 Universal horary quadrants on European astrolabes

The markings of type 1 sometimes appear on European astrolabes, at least from the 14th century onwards, and further research would be necessary to investigate whether European astronomers realised that the markings were approximate and/or did not work so well for northern latitudes.

On the earliest European astrolabes the markings do not occur. The universal horary markings appear on Catalan, French, Italian and German astrolabes in the 14th century, being standard on the Fusoris instruments in Paris *ca*. 1400, but not on astrolabes from 15th-century Vienna, for there a whole new set of appendages was available. They are not generally found on medieval English astrolabes (where tables of saints' days in the Chaucer tradition were sometimes preferred), but they do feature on contemporaneous English *navicula*s (inevitably together with the shadow square).[1] They feature very frequently on 16th-century German astrolabes (especially Hartmann and Praetorius), but rarely on 16th-century Louvain or Elizabethan English astrolabes.

Already in the 14th century, if not before, we find the markings doubled to serve all the hours of daylight: see **Fig. 12a**.[2] The construction of a double set reduces for hours 1-5 to joining triads of points with circular arcs and presents a pleasing aspect, not least because the now full circle for the 6th hour can be used to accommodate an inscription or whatever: see **Fig. 12b**.[3] Rarely, however, does one find an intelligent use of the universal markings next to a set of latitude-specific markings: see **Fig. 12d**.[4]

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l-w kh-m-s-t-m-ʾ-y-h), such mixed forms of writing numbers being highly unusual. The author, Abu ʻl-Ḥasan ʿAlī ibn Muḥammad known as Ibn al-Ḥammāmī, makes no claim to have invented the instrument. The treatise precedes by 200 years the earliest surviving examples, on which the best studies are Morley, "Arabic Quadrant", and Dorn, "Drei arabische Instrumente", pp. 16-26.

[2] #5021—signed by Aḥmad ibn ʿAbd al-Raḥmān al-Dahmānī and dated 854 H [= 1450/51]—Madrid, Museo Arqueológico Nacional, inv. no. 50856, electrotype copy in the Science Museum, London, inv. no. 1877-5—see Mayer, *Islamic Astrolabists*, p. 34, and the bibliography there cited.

[1] **XIIb-9a-c**.

[2] #193—Chicago, Adler Planetarium, inv. no. W-264—see *Chicago AP Catalogue*, I, pp. 46-48 (no. 3).

[3] The illustration of Apian is found in Gunther, *Astrolabes*, II, p. 453, and Röttel, ed., *Peter Apian*, p. 141. For other examples see *ibid*. (* indicates facing page), pp. 325, 331, 335, 425*, 429*, 432, 436*, 437*, 438*, 443*, 460* and 503. See also *Rockford TM Catalogue*, p. 5, for an illustration of "un soleil ridicule" inside a double horary quadrant in the treatise of Jacques Focard, Lyons, 1555.

[4] #337—Greenwich, National Maritime Museum, inv. no. A34/36-28C—the first description is to appear in *Greenwich Astrolabe Catalogue*.

Fig. 12a: The universal horary markings on a typical astrolabe (#193) of the atelier of Jean Fusoris in Paris *ca*. 1400. On instrument-making in medieval Northern France see King, *Ciphers of the Monks*, pp. 391-419. It seems that the Europeans in the Middle Ages had know idea why these markings worked, or, to put it another way, they had know idea that these markings did not work at all well in Northern Europe. [Courtesy of the late Roderick Webster, Adler Planetarium, Chicago.]

Fig. 12b: Above the universal horary markings on this astrolabe illustrated by Peter Apian we find the image of a king representing the sun. In his hand, he holds a set of six labelled asterisms for the moon and five naked-eye planets. (In other such images, he is depicted in full with one foot on a large feline representing Leo, the domicile of the sun—see **Fig. 12c**) It was no doubt through such illustrations that the notion "planetary hours" became engrained in the Renaissance mind, a far notion from the original function of the horary markings in 9th-century Baghdad. But this was not the end of the road: alas, I could not lay hands on an illustration that I once found in a printed astrolabe text in which the sun becomes a woman with a Struwwel-peter-type mop of hair, wearing a very feminine dress, and brandishing a bunch of unlabelled party balloons. [From Apian, *Cosmographia*, 1574 edn., p. 9.]

Fig. 12c: Here the sun and its dependents are illustrated within the solar and calendrical scale but without the horary quadrant. Compare **Fig. 12b**. [From Apian, *Cosmographia*, *ca*. 1550; see also Röttel, ed., *Peter Apian*, pp. 140-141.]

Fig. 12e: The circle for midday on these quadrants on the back of this 15th-century quatrefoil astrolabe (#3000) is incorrectly drawn. Also, on the left hand side, the maker has inserted some curious markings which appear to have no astronomical significance. Photographs of the backs of astrolabes often have the alidade covering the most interesting markings; the alidade should be photographed alongside the back, not on it. [Courtesy of the Historisches Museum, Basle.]

Fig. 12d: A sensible use of the universal markings, together with a set of horary markings for an unspecified latitude, found on what has been thought to be an English astrolabe, but which is clearly in the French tradition (#337). The latter serve a latitude of *ca*. 48°, and help locate the maker in Northern France. The mater and a single plate serve [50°], 51;34° [London], and 52° [Oxford, *etc*.]. On latitudes used in astronomical instrumentation in medieval England, see **XIIb-9e**. [Courtesy of the National Maritime Museum, Greenwich.]

Virtually all of the universal horary markings on European astrolabes and quadrants are properly drawn. In a 15th-century Latin manuscript from Spain, however, we find a carelessly-drawn diagram of two universal horary quadrants.[5] And on a 15th-century astrolabe of uncertain provenance we find the markings on a double universal horary quadrant has come unstuck: see **Fig. 12e**.[6]

13 Universal horary markings on European quadrants

The European tradition of the *quadrans vetus* begins in the 12th and 13th centuries, and that of the *quadrans novus* towards the end of the 13th. There was also a tradition of universal horary quadrants without a complete solar scale. A single example is a wooden quadrant,

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[5] Villena, *Astrología*, fig. 15 on p. 169. On fig. 14 on p. 168 there is a better diagram of two sets of universal horary markings of type 2.

[6] #3000—Basle, Historisches Museum, inv. no. ?—unpublished.

probably Italian and perhaps from the 15th century, with an unsuccessful attempt at placing some sort of solar markings on one of the radii: see **Fig. 7c**.[1]

The influence of the *quadrans vetus* markings on three 14th-century English latitude-specific horary quadrants (all for latitude *ca*. 52°) is clearly visible.[2] The quadrants are each marked for the equinoctial hours, but *midday is represented by a complete semi-circle*, and on one piece there is even a superposed shadow square. The horary markings are all arcs of circles. Originally there was no solar scale, simply quarter-circles for the equinoxes and solstices. On one piece the English instrument-maker Charles Whitwell added *ca*. 1595 a non-uniform solar scale and more quarter-circles for each 10° of solar longitude.[3] See further **14**.

In the Portuguese astrological and navigational manual *Reportorio dos tempos* by the German scholar-printer Valentim Fernandez (1563) a small universal horary quadrant with (distorted?) shadow square is illustrated inside the main radial markings of a seaman's altitude quadrant.[4] Fernandez' source was a Castilian treatise published in Seville in 1495. I do not know whether this form of the altitude quadrant became popular amongst navigators.

On 16th-century English (Elizabethan) instruments the markings are labelled "*horae planetarum*" or "*the ours of planet9*", referring to a Hellenistic association of the seasonal hours with the planets (a far cry from the purpose of the Baghdad treatise), revived in the Middle Ages, notably by Geoffrey Chaucer, who was surely familiar with the tables of the planets associated with the hours in contemporaneous astronomical tables, such as those of Nicholas of Lynn.[5] See **Fig. 13a** for a table published by Peter Apian.

On some late European universal horary quadrants the outer parts of the markings are suppressed, because the sun never reaches them.[6] On others they are curved in a decorative fashion at the ends: see **Fig. 13b**.[7]

These instruments and their horary markings confirm Emmanuel Poulle's recent demonstration that the seasonal hours had an afterlife in Europe long after the introduction of mechanical clocks.[8]

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[1] #5501—Milan, until recently in a private collection in Milan, present location unknown—unpublished.

[2] #5521—dated 1398—Dorchester, Dorchester Museum, inv. no. ?—see *London BM Catalogue*, pp. 55-56 *ad* no. 146, and pls. XVIIb and XVIIIb.

#5522—dated 1399—London BM, inv. no. 60 5-19 1—see *ibid*., pp. 55-56 (no. 146) and pls. XVIIa and XVIIIa, and the next note.

#5523—undated, early 15th century (?)—London BM, inv. no. 56 6-27 155—see *ibid*., p. 56 (no. 147).

These three pieces are now studied in Ackermann & Cherry, "Three Medieval English Quadrants".

[3] On these markings on #5522 see G. Turner, "Whitwell's Addition to a 14th-Century Quadrant", and *idem*, *Elizabethan Instrument Makers*, no. 44 at pp. 190-191. This should lay to rest the suspicion voiced by Derek Price that the English quadrants were fakes (Price, "Instruments in the British Museum", p. 131).

[4] Waters, "Renaissance Navigation", fig. 3 on p. 8, and the text on p. 9.

[5] See *ibid*., pp. 83, 97-98, 100, 130-131, 133, 160 and 163, and also Eisner, ed., *Kalendarium of Nicholas of Lynn*, pp. 176-177 and the commentary on pp. 17-18; North, *Chaucer's Universe*, pp. 77-79; and Stöffler, *Elucidatio*, p. 43v. On the medieval association of the hours with the planets see also Gunther, *Science in Oxford*, V, pp. 50-51; Ginzel, *Handbuch der Chronologie*, III, p. 97; K. & S. Maurice, "Counting the Hours", p. 147; and Gouk, *Ivory Sundials of Nuremberg*, p. 19.

[6] This explains the remark of G. Turner (*ibid*., p. 98) concerning an Elizabethan instrument: "small horary quadrant, seemingly for unequal hours but terminated too soon".

[7] For another example see van Cittert, *Utrecht Astrolabes*, pl. XVIII, reproduced in Viladrich, "Horary Quadrants", pl. V on p. 345.

[8] Poulle, "Heures inégales".

Taffel der regierung der Planeten nach den vngleichen stunden des Tags.

Planetenstund	1	2	3	4	5	6	7	8	9	10	11	12
Sontag	☉	♀	☿	☽	♄	♃	♂	☉	♀	☿	☽	♄
Montag	☽	♄	♃	♂	☉	♀	☿	☽	♄	♃	♂	☉
Erichtag	♂	☉	♀	☿	☽	♄	♃	♂	☉	♀	☿	☽
Mittwoch	☿	☽	♄	♃	♂	☉	♀	☿	☽	♄	♃	♂
Donnerstag	♃	♂	☉	♀	☿	☽	♄	♃	♂	☉	♀	☿
Freytag	♀	☿	☽	♄	♃	♂	☉	♀	☿	☽	♄	♃
Sambstag	♄	♃	♂	☉	♀	☿	☽	♄	♃	♂	☉	♀

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Taffel der regirenden Planeten zu Nacht nach außtaylung der vngleichen stund.

Vngleich stund	1	2	3	4	5	6	7	8	9	10	11	12
Sontag	♃	♂	☉	♀	☿	☽	♄	♃	♂	☉	♀	☿
Montag	♀	☿	☽	♄	♃	♂	☉	♀	☿	☽	♄	♃
Dinstag	♄	♃	♂	☉	♀	☿	☽	♄	♃	♂	☉	♀
Mittwoch	☉	♀	☿	☽	♄	♃	♂	☉	♀	☿	☽	♄
Donnerstag	☽	♄	♃	♂	☉	♀	☿	☽	♄	♃	♂	☉
Freytag	♂	☉	♀	☿	☽	♄	♃	♂	☉	♀	☿	☽
Sambstag	☿	☽	♄	♃	♂	☉	♀	☿	☽	♄	♃	♂

Fig. 13a: Apian's table for the planets associated with the seasonal hours of day and night. [From his *Instrument Buch* (1533). See also Röttel, ed., *Peter Apian*, pp. 91-92.]
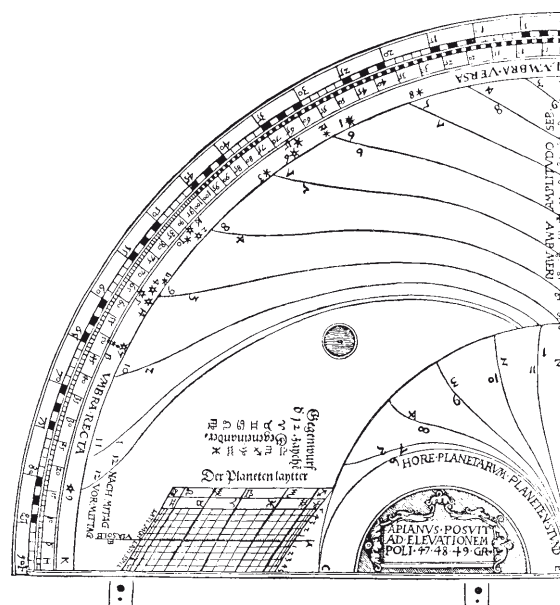
Fig. 13b: One of four horary quadrants for a specific latitude (or rather, a small range of latitudes) proposed by Peter Apian. Note the decorative ends on the universal horary curves in regions outside the solar range. [From his *Instrument Buch* (1533). See also Röttel, ed., *Peter Apian*, pp. 91-92.]

14 On the provision of a latitude-dependent solar scale

On some European astrolabes from the 15th (?) century onwards, the universal horary markings are forcibly restricted to a single latitude by inserting a latitude-dependent solar scale either on one or both of the radii of the quadrant or on an alidade, as well as corresponding quarter-circles for, say, the equinoxes and each solstice.[1] Two examples must suffice: an illustration by Stöffler (**Fig. 14a**) and a 16th-century Italian astrolabe (**Fig. 14b**).[2] Whilst this to some extent violates the spirit of the instrument,[3] as well as compromising the aesthetic consideration that

[1] General discussions of such scales are in Michel, *Traité de l'astrolabe*, pp. 82-85, and Fantoni, *Orologi solari*, pp. 357-370. For a discussion relevant to Islamic horary quadrants see now Charette, *Mamluk Instrumentation*, pp. 118-124.

[2] #4570—Oxford, Museum of History of Science, inv. no. 26—unpublished, not listed in Price *et al.*, *Astrolabe Checklist*.]

[3] Henri Michel (*Traité de l'astrolabe*, pp. 81-85) could not resist forcing a solar scale on the markings. John North appears to see this as the only salvation of the horary markings. In his otherwise splendid 1974 paper on the astrolabe, in the diagram of the back of a "standard" astrolabe, he mistakenly inserted a solar scale on the alidade (North, "Astrolabe", p. 105, with the following—now appropriate—remark in the caption: "these lines are to be used in conjunction with the graduations on the alidade"). In his study "Hour-Line Ritual", North took this misconception to its logical conclusion. His firm belief that the universal horary quadrant without a solar scale is non-functional is questioned already in McCluskey, *Medieval Astronomy*, p. 174, n. 27: "I find (North's) scepticism overdrawn, since these curves could have been used without such graduations by marking the noontime height of the Sun."

Similarly, Harold Saunders (*All the Astrolabes*, pp. 20-27) could not rest without the solar scale. Indeed, his

Fig. 14b: On this Italian astrolabe made in 1558 (#4570) the double universal quadrant has been provided with a radial solar scale on the alidade and circular arcs for the solar declination on the quadrants themselves. The underlying latitude is *ca*. 45°. The markings are *completely superfluous* because the (one and only ?) plate inside the astrolabe is for 44;30°. [Courtesy of the Museum of History of Science, Oxford.]

Fig. 14a: Johannes Stöffler in 1524 presented this unhappy combination of approximate and exact markings, as if one should use the full approximate universal markings with the solar scale to find the time in seasonal hours for the latitude (49°) underlying the solar scale, and the shortened horary markings to find the time in equinoctial hours. The two sets of markings should not be superposed. [From Ioannis Stoflerinus, *Elucidatio fabricae vsvsqve astrolabii*, Oppenheim, 1524, p. 27v.]

perhaps one should not combine universal and latitude-specific solutions directly, the horary markings themselves can still be used universally without the solar scale. But the inclusion of a solar scale cannot overcome the approximate nature of the solution provided by the basic markings. The same kind of additional solar scale occurs on some late Iranian astrolabes, possibly as a result of (rather misguided) European influence,[4] possibly the result of renewed independent interest in quadrants amongst Iranian astronomers.[5] One reason for not putting

fig. 25 on p. 26, which shows the (approximate) universal horary markings for the seasonal hours with a latitude-specific solar scale superposed, as well as a set of (exact) latitude-specific horary curves, supposedly for conversion of one kind of hours to the other, is labelled: "The confusion resolved." In fairness to Saunders, it should be noted that. Stöffler 450 years before him published a diagram of precisely the same kind—see **Fig. 14a**—and for the same purpose, but also Stöffler seems to have been unaware that the universal horary markings were based on an approximate formula.

[4] On other kinds of European influence on Iranian instruments see King, *Mecca-Centred World-Maps*, pp. 275-328. Yet maybe the markings are not European-inspired, but rather were conceived as a result of the rediscovery of the Baghdad treatise in Meshed *ca*. 1800 (see nn. 2:1 and 5:3).

[5] The time was ripe, and it was not too late. Iranian astronomers over the centuries had not appreciated the quadrant as had their counterparts elsewhere in the Islamic world. Apart from quadrants on astrolabes, only one instrument in the form of a quadrant survives from Iran: this is an horary quadrant for latitude 36° and dates from *ca*. 1285 (not from the 10th century as I have claimed elsewhere)—see my article "Rubʿ" [= quadrant] in EI_2, VIII, p. 574b and pl. XXXII, *idem*, "Cataloguing Islamic Instruments", col. 255, and now **XIIIc-13**. Furthermore, only two treatises on the quadrant survive in Persian, compared with dozens in Arabic: see *Cairo ENL Survey*, p. 166 (no. G120), and King, "al-Khwārizmī", pl. 9 on p. 28.

the solar scale on the alidade itself was to leave space for a sexagesimal scale to serve other trigonometric quadrants or to include a universal sundial on the alidade (see **App. C**). For astrolabes made for Northern Europe, it was better to insert one or two latitude-specific horary quadrants,[6] but the universal markings were generally preferred on astrolabes even in Northern climes simply because they were universal.[7]

15 Concluding remarks

We have shown how the origin of the *quadrans vetus* is to be found in 9th-century Baghdad. We have to some extent been able to document the fate and fortunes of the universal horary quadrant in later centuries. (I see that I have not mentioned Sacrobosco, but Delambre, quoted at the beginning of this paper, said enough.) And we have shown that the markings have a rightful place on the back of the astrolabe, for on most astrolabes, Islamic and European, the universal horary markings are correctly rendered and serve beautifully the purpose for which they were originally intended (even though the error in Northern Europe might reach 20 minutes). Their inclusion on some groups of astrolabes became something of a ritual, but on serious instruments, of which we have plenty, it was never an "empty ritual" for those who knew how to use them.[1] It was, however, as I have shown, to some extent a ritual limited both in time and place.[2] Whether they were ever used for the purpose our Baghdad astronomer intended is another matter, but there was certainly no reason why they should not have been.

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[6] Viladrich (see nn. 1:11 and 9:1) also deals with some late European horary quadrants.

[7] Note the inclusion of universal markings even on Dutch latitude-specific horary quadrants from the 17th century (see Viladrich, "Horary Quadrant", pp. 318-323). Ernst Zinner ("Wissenschaftliche Instrumente", p. 69) records that universal horary quadrants in wood (he calls them *quadrantes vetustissimi*) were still being made in Sweden in the 18th century; one wonders whether they were ever used there by anybody sober.

[1] North, "Hour-Line Ritual", found at most 6 out of some 40 astrolabes with universal horary markings (out of a total of some 130 which were available to him in Oxford) to have "proper" markings of this kind, where "proper" refers to a latitude-specific solar scale, and only one of these he found to be properly executed.

I would maintain that, apart from those which are incompetently made, *all* of the universal horary markings examined by North are perfectly functional with an unmarked alidade. Future students in the Oxford Master's program in the History of Science should be encouraged to check this by using a small piece of chewing-gum on the alidade of any astrolabe with such markings. Alas they will not be able to take the instruments to Santiago de Compostella or Jerusalem, for there they would find that the markings work even better than in Oxford.

[2] I have examined several hundred Islamic astrolabes and quadrants and over one hundred European ones from before 1500. These are but a small fraction of those actually made, but a very large fraction of those known. I have summarised my findings in the text of this paper. In any more detailed investigation, care must be taken to distinguish between different layers of markings, as the following two examples show.

On the back of the Oxford astrolabe by the brothers Aḥmad and Muḥammad sons of Ibrāhīm al-Iṣfahānī dated 374 Hijra [= 984/85], (#3—Oxford, Museum of the History of Science, inv. no. ICC 3—see Gunther, *Astrolabes*, I, pp. 114-116 (no. 3), and now **XIIIc-10**), there is an original inscription *al-sāʿāt al-zamāniyya li-kull ʿarḍ*, "(for finding) the seasonal hours for all latitudes", written vertically to the right of the sine quadrant in the upper left quadrant of the back. It is not clear to me from photographs whether any original markings of type 1 in the upper right quadrant have been eradicated to make room for the later layer of astrological information which now covers each of the other three quadrants, or whether this inscription refers only to the sine quadrant in the upper left. See further **XI-9.3**. Likewise, the universal horary markings do not occur on the original astrolabes of al-Khamāʾirī (Seville *ca*. 1200). One astrolabe by him, (#1148—dated 628 H [= 1230/31]—Cairo, Museum of Islamic Art, inv. no. 15371—unpublished), has such markings, but these were added by a European in the 15th century. Early Andalusī astrolabists preferred a variety of serious trigonometric grids on the backs or on the plates of their astrolabes (see nn. 6:2 and 10:2).

ذكر العمل بربع الدائرة وهذه أبوابه

[١] في معرفة خطوطه وأسمائها اعلم أنّ الربع ربع دائرة تامّة والأوّل من خطوطه الخطّان اللّذان يتقاطعان على المركز أحدهما يسمّى خطّ المشرق والآخر خطّ نهاية الارتفاع وفيما بين هذين الخطّين[1] في محيط الربع أجزاء مقسومة متساوية وهي تسعون جزءا < … > تسمّى المجرة[2] وتعمل في بعض الأرباع متحرّكة وفي بعضها ثابتة ثم دونها ستّة خطوط مقوّسة[3] وهي قطع دوائر تسمّى الساعات الزمانية وقد تعمل هذه الخطوط في بعض الأرباع مستقيمة وفي بعضها أقطارًا تخرج[4] من مركز الربع والعمل بالكلّ سواء ثم مربّع الظلّ وكلّ ضلع من المربّع مقسوم باثنى عشر قسمًا يسمّى الضلع القائم على خطّ نهاية الارتفاع الظلّ المبسوط والآخر الظلّ[5] المنكوس وفي رأس الربع زيادتان فيهما ثقبان يسمّيان الدفّتين ويخرج من مركز الربع خيط فيه شاقول وفي الخيط عقدة متحرّكة تسمّى المري فهذا ما في الربع من الخطوط فاعلمه

[٢] في أخذ الارتفاع أيّ وقت شئت تمسك الربع بيدك وتحاذي بمنكبك وتحرف الربع القائم جرم الشمس ثم لا تزال تحرّك الربع صاعدًا ونازلًا حتّى ينفذ شعاع[6] الشمس من ثقب الدفّة العليا إلى ثقب الدفّة الأخرى وليكن إرسال الشاقول مع سطح الربع فإذا سكن الشاقول انظر كم قطع الخيط من درج الارتفاع فعدّ من خطّ المشرق والمغرب إليه فما كان فهو الارتفاع في ذلك الوقت

[٣] في معرفة ميل الشمس إذا أردت ذلك فاعرف اليوم الذي تريد ميل الشمس فيه من أيّ شهر يكون فضع الخيط على مثل ذلك اليوم من ذلك الشهر ثم انظر ما بين الخيط وخطّ نصف المجرة وهو خطّ الاعتدال من الدرج فما كان فهو ميل الشمس في ذلك اليوم فإن كان يومك فيما بين خطّ الاعتدال وخطّ المشرق والمغرب فالميل جنوبي وإن كان فيما بين خطّ[7] الاعتدال وخطّ نهاية الارتفاع فهو شمالي

[٤] في معرفة الماضي من النهار من الساعات الزمانية والظهر والعصر في كلّ زمان إذا أردت ذلك فضع الخيط على يومك في المجرة ثم حرّك المري حتّى تضعه على خطّ نصف النهار وهذا الخطّ الثالث فإذا عدّلته حدد[8] ارتفاع الشمس كما تقدّم ثم انظر أين وقع المري من الساعات فما كان فهي الساعات المارّة من النهار إن كانت[9] الشمس مشرقة وإن كانت مغربة فهي الساعات الباقية من النهار فتنقصها من اثنى عشر تبقى الساعات الماضية من النهار كذلك تعرف وقت الظهر والعصر بأن تأخذ الارتفاع فإذا وقع [9r] المري على خطّ نصف النهار فهو أوّل الظهر وكذلك إذا وقع على خطّ العصر والشمس مغربة فهو أوّل وقت العصر

[٥] في معرفة الظلّ المبسوط والمنكوس إذا أردت ذلك فاعرف ارتفاع الشمس كما تقدّم ثم انظر ما يقع عليه الخيط من الظلّ المبسوط إن أردته أو المنكوس فما كان فهو الظلّ لذلك الوقت فإن أردت الظلّ المبسوط ووقع الخيط في الظلّ المنكوس فاقسم عليه أبدًا مائة وأربعة وأربعين يخرج من القسمة الظلّ المبسوط فاعلم ذلك

[٦] في معرفة ارتفاع نصف النهار وارتفاع أوّل العصر في كلّ فصل إذا أردت ارتفاع أوّل الظهر فضع الخيط على اليوم

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[1] وفيما بين هذين الخطّين] *bis* MS [2] المجرة] المحرة MS [3] مقوّسة] معسو مقوسة MS [4] تخرج] يخرج MS [5] الظلّ] ظل MS [6] شعاع] الشعاع MS [7] خطّ] *bis* MS [8] حدد] حد MS [9] إن كانت] *bis* MS

الذي تريد فما قطعه الخيط من درج الارتفاع فهو ارتفاع نصف نهار ذلك اليوم وأمّا الارتفاع أوّل العصر فإنّك تعدّل المري على خطّ نصف النهار على ما تقدّم ثم تضعه أعني المري على خطّ العصر فما يقع عليه الخيط من الارتفاع فهو ارتفاع أوّل العصر

[٧] في معرفة الظلّ المبسوط لأوّل وقت الظهر وأوّل وقت العصر إذا أردت فاعرف ارتفاع أيّهما[10] أردت على ما تقدّم وضع الخيط في الأصابع فما كان فهو الظلّ لذلك الوقت فإن وقع الخيط على الظلّ المنكوس لأوّل الظهر والعصر < . . . > فاعلم ذلك

[٨] في معرفة الأقدام إذا كانت معك أصابع وأردت أن تردّها أقداما فاضربها أبدًا في سبعة فما اجتمع فاقسمه على اثنى عشر تخرج من القسمة الأقدام لتلك الأصابع وكذلك إذا كانت معك أقدام وأردت أن تردّها أصابع فاضرب ما معك من الأقدام في اثنى عشر واقسمها على سبعة تخرج أصابع تلك الأقدام

[٩] في معرفة عرض البلد إذا دخلت بلدًا وأردت معرفة عرضه فخذ ارتفاع الشمس أرفع ما يكون بالرصد واحفظه[11] ثم اعرف ميل الشمس كما أعلمتك فإن كان جنوبيًا نقصته من ارتفاع الشمس نصف النهار وإن كان شماليًا زدته فما بلغ أو بقي فهو ارتفاع المعدّل فانقصه أبدًا من تسعين فما بقي فهو عرض ذلك الموضع واعلم أنّ المجرة المتحرّكة لا يعمل بها حتّى تعمل على مثل عرض البلد فأمّا الثابتة[12] فهي موضوعة[13] على عرض مخصوص فإذا أردت معرفة العرض الذي وضعت المجرة الثابتة عليه فانظر إلى خطّ نصف المجرة وهو خطّ الاعتدال على كم وقع من الارتفاع فما كان انقصه من تسعين فما بقي فهو عرض البلد الذي عملت له المجرة الثابتة وعرض هذه المجرة لج

[١٠] في معرفة كيفيّة العمل بالمجرة المتحرّكة أو الثابتة في جميع البلاد فإذا[14] دخلت بلدًا وأردت أن تعمل بالربع فاعرف عرض ذلك البلد على ما تقدّم ثم ضع خطّ نصف المجرة وهو خطّ الاعتدال على مثل ذلك العرض وهو أن تعدّ من خطّ نهاية الارتفاع مثل ذلك العرض وتضع المجرة على متهى العدد ثم اعمل بها ما تقدّم من الأعمال فإن لم تكن[15] المجرة على عرض البلد لا يصحّ معك العمل فأمّا المجرة الثابتة فتعرف عرض البلد الذي عملت له المجرة الثابتة وتحفظه فإذا دخلت مدينة فاعرف عرضها فإن كانا متساويين فاعمل بالمجرة الثابتة على ثباتها بلا زيادة ونقصان وإن كان عرض البلد الذي دخلته أزيد من عرض البلد الذي أثبتت[16] فيه المجرة فاحفظ فضل ما بينهما وحرّك الخيط من يومك بمقدار هذه الفضلة إلى جهة خطّ المشرق والمغرب فيقع الخيط على يوم المعدّل لذلك البلد وإن كان عرض البلد الذي دخلته[17] انقص من عرض البلد الذي أثبتت[18] فيه المجرة فحرّك الخيط من يومك بقدر فضل ما بين العرضين إلى جهة خطّ نهاية الارتفاع فيقع الخيط على اليوم المعدّل لذلك البلد فاعرف ذلك وفّقك الله وهذه صورته

10 أيّهما] ايتهما MS 11 واحفظه] واحفظ MS 12 الثابتة] الثانية MS 13 موضوعة] موضعة MS 14 فإذا] اذا MS 15 تكن] يكن MS 16 أثبتت] اثبت MS 17 دخلته] دخلت MS 18 أثبتت] اثبت MS

MS Cairo DM 969,4 (fols. 8v-9v)

Translation

Notes: Arabic words in parentheses are the corresponding technical terms in the original. English words in parentheses are inserted to ensure the flow of the translation. Text in square brackets corresponds to lacunae in the Arabic text. Remarks in curly brackets are my comments.

A treatise on the use of the quadrant

A statement concerning the use of the quadrant (*rubʿ al-dāʾira*). These are the ways it can be used (*abwābuhu*):

[1] On its markings (*khuṭūṭ*) and their names. The quadrant is a quarter of a complete circle. The first of its markings are the two lines that intersect at the centre, one of which is called the east(-west) line (*khaṭṭ al-mashriq*) and the other the meridian line (*khaṭṭ nihāyat al-irtifāʿ*). In between these two lines around the circumference of the quadrant there are equal divisions which make up ninety degrees. ... ... {LACUNA}; this is called the cursor (*al-majarra, sic* for *al-majrā* ?) and it is made movable in some quadrants and fixed in others (*tuʿmal fī baʿḍihā mutaharrika wa-fī baʿḍihā thābita*). Below (the cursor) there are six curved lines that are segments of circles called the seasonal hours (*al-sāʿāt al-zamāniyya*). On some quadrants these markings are made straight and on others (they are made) radii (*aqṭār*) radiating from the centre of the quadrant. The use of all of these is the same.

Then (there is) the shadow square (*murabbaʿ al-ẓill*), each side of which is divided into twelve parts. The side standing on the meridian line is called the horizontal shadow (*al-ẓill al-mabsūṭ*), and the other the vertical shadow (*al-ẓill al-mankūs*). On the upper side (*raʾs*, lit., head) of the quadrant there are two parts which stick out (*ziyādatāni*) with two holes {*i.e.*, one each} called the sights (*daffa*). A thread bearing a plummet (*shāqūl*) extends from the centre of the quadrant, also bearing a movable bead (*ʿuqda*, lit., knot!) called the marker (*al-murī*). These are the markings on the quadrant, so know this.

[2] On measuring the altitude at any time you wish. You hold the quadrant in your hand, line (it) up with your shoulder, and turn the now vertical quadrant towards the sun. Then you keep moving the quadrant up and down until the solar rays pass through the hole on the upper sight to (fall on) the hole on the other sight. (Also) the plummet should hang properly (*irsāl*) on the surface of the quadrant. When the plummet is still, see how many degrees of altitude are marked off by the thread, then count from the east-west line to that (point), and the result will be the altitude at that time.

[3] On finding the declination of the sun. If you want to do this, find the day on which you want the declination of the sun, whatever month it is in, and place the thread on that day of the month. Then look at how many degrees are between the thread and the line (joining the centre to) the middle of the cursor, which is the equinox line. The result will be the declination of the sun on that day. If your day is between the equinox line and the east-west line, then the declination is southerly; if it is between the equinox line and the line of the limit of the altitude, then (the declination) is northerly.

[4 corrupt] On finding the time of day elapsed in seasonal hours, and the (times of) the *ẓuhr* and the *ʿaṣr* (prayers) at any time (of the year). If you want this, place the thread on your day

on the cursor and then move the marker until you place it on the meridian line, which is the third line (??). Then if you adjust it, fix the altitude of the sun as (described) previously. Then look where the marker has fallen on the hours, and this will be the hours of daylight passed if the sun is in the east; if (the sun) is the west, it will be the hours of daylight remaining, so you subtract it from twelve and the remainder will be the hours of daylight passed.

[4b corrupt] Likewise you find the time of the *ẓuhr* and the *ʿaṣr* by taking the altitude and if the marker falls on the meridian line, it will be the beginning of the *ẓuhr*. Similarly, if it falls on the *ʿaṣr* line and the sun is in the west, it will be the beginning of the time of the *ʿaṣr*.

[4 reconstructed] On finding the time of day elapsed in seasonal hours, and the (times of) the *ẓuhr* and the *ʿaṣr* (prayers) at any time (of the year). If you want this, place the thread on your day on the cursor and then move the marker until you place it on the meridian line. Then if you adjust it, fix the altitude of the sun as (described) previously. Then look where the marker has fallen on the hours, and this will be the hours of daylight passed if the sun is in the east; if (the sun) is the west, it will be the hours of daylight remaining, so you subtract it from twelve and the remainder will be the hours of daylight passed.

[4b reconstructed] Likewise you find the time of the *ẓuhr* and the *ʿaṣr* by (first) taking the altitude when the marker falls on the meridian line: this will be the beginning of the *ẓuhr*. Similarly, if it falls on the *ʿaṣr* line, which is the third hour line, and the sun is in the west, it will be the beginning of the time of the *ʿaṣr*.

[5] On finding the horizontal and vertical shadows. If you want this, find the altitude of the sun as (described) previously and then look where the thread falls on the horizontal shadow (scale) if you want that or on the vertical shadow (scale) (if you want that). The result will be the shadow at that time. If you want the horizontal shadow and the thread has fallen on the vertical shadow, divide it into one hundred and forty-four and the resulting quotient will be the horizontal shadow, so know this.

[6] On finding the altitude at midday and the altitude at the beginning of the *ʿaṣr* at any time of the year. If you want the altitude at the beginning of the *ẓuhr*, put the thread on the day you want (on the cursor) and the amount of altitude degrees the thread cuts off will be the altitude at midday on that day. The altitude at the beginning of the *ʿaṣr* (is found as follows). You adjust the marker on the meridian as (described) previously, then you place it, that is, the marker, on the *ʿaṣr* line. Where the thread falls on the altitude (scale) will be the altitude of the beginning of the time of the *ʿaṣr*.

[7] On finding the horizontal shadow at the beginning of the times of the *ẓuhr* and *ʿaṣr*. If you want, find the altitude of whichever one of the two you wish as (described) previously, and place the thread on the digits (of the shadow scale) and the result will be the shadow at that time. If the thread falls on the vertical shadow (scale) at the beginning of the *ẓuhr* and the *ʿaṣr*, ... {LACUNA} , so know that.

[8] On finding (the shadow in) feet if you know (the shadow) in digits and you want to convert it to feet. Multiply (the digits) by seven and divide the product by twelve: the quotient will be the feet corresponding to those digits. Likewise, if you have (the shadow in) feet and

you want to convert it to digits; multiply the feet you have by twelve, divide (the product) by seven, and the result will be the digits corresponding to those feet.

[9] On finding the local latitude. If you come to a locality and you want to know its latitude, observe the altitude of the sun when it is at its highest and keep it in mind. Then find the declination of the sun as I have told you, and if it is southerly subtract it from the altitude of the sun at midday, and if it is northerly add it. The result of addition or subtraction will be the altitude of the celestial equator: subtract it from ninety and the remainder will be the latitude of that place. Know that the movable cursor is not to be used until it has been placed on the equivalent of the local latitude (on the altitude scale). The fixed cursor is set at a particular latitude. If you want to know the latitude for which the fixed cursor is set, look at the line (from the centre to) the middle of the cursor, which is the line of the equator, (and see) where it falls on the altitude (scale). Subtract this from ninety and the remainder will be the local latitude for which the fixed cursor was made. The latitude of this cursor {in the illustration that follows?} is 33°.

[10] On the method of using the movable or fixed cursor in all localities. If you come to a locality and you want to work with the quadrant, find the latitude of that locality as (described) previously. Then place the line (joining the centre) to the middle of the cursor, which is the equinox line at that latitude, by counting the latitude from the meridian line and placing the cursor at the argument that you reach. Then perform with it the operations that have been described previously. If the cursor is not set at the local latitude, then the operations are not correct. With regard to the fixed cursor, find the local latitude for which it was made and keep it in mind. If you enter any town determine its latitude, and if the two (latitudes) are the same, work with the fixed cursor as it is without modification. If the latitude of the locality you entered is greater than the latitude for which the cursor is fixed, keep in mind the difference between them and move the thread from your day by the amount of this difference in the direction of the east-west-line so that the thread falls on the day adjusted for that locality. If the latitude of the locality you entered is less than the latitude of the locality for which the cursor was fixed, move the thread from your day by the difference between the two latitudes in the direction of the meridian line, and the thread will fall on the day adjusted for that locality. Know this and may God grant you success. This is an illustration of (the quadrant): {BLANK}.

Commentary

Introduction: The term *bāb*, pl. *abwāb*, is often used in Arabic technical texts in the sense of "method", rather than the standard meaning "chapter" (literally "door"). In the manuscript there are empty spaces that normally might be filled with the chapter numbers (*al-bāb al-awwal*, "the first chapter", *etc*.) in red ink. However, I doubt that the chapters were numbered in the 9th-century text; perhaps all that is missing each time is the word *bāb*, "chapter".

Ch. 1: The terminology is eminently sensible and in its time set new standards for the field.[1] Here and elsewhere for the movable cursor in its groove the manuscript has *al-m-j-r-h*, perhaps

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[1] On some of the terms see Kunitzsch, "Fachausdrücke der Astrolabliteratur".

to be read *al-majarra* (root *j-r-r*, "to pull"), and meaning "a place or path where something is pulled"; this is perhaps an error for *al-majrā* (written *m-j-r-y*, *root j-r-y*, "to run"), which literally means "a place for running" and would be singularly appropriate if applied to the groove.[2] The word *al-majarra* is used for the Milky Way in Arabic.[3] One could argue that a Persian-speaker rather than an Arabic-speaker would be more likely to mistakenly write the word pronounced *majrā* as *m-j-r-h*. On the other hand, *m-j-r-h* is treated consistently (and correctly) as feminine in the manuscript, whereas *majrā* is masculine. In the 14th-century Topkapı manuscript of al-Marrākushī's work (see **Fig. 5a**), the term used for the cursor on the sine quadrant on the back of the *zarqāllī* quadrant is *m-j-r-h*, sometimes with a *shadda* on the "r" (to double the "r").[4]

Ch. 4: See **Fig. 3a** for the basic procedures to find T(h,H). The text is corrupt and I have restored the meaning in the translation. If my restoration of this chapter is correct (see below *ad* Ch. 7), our author takes the beginning of the *ẓuhr* as midday and the beginning of the *ʿaṣr* as the middle of the afternoon, using the "third line". I know of no other medieval Arabic astronomical texts proposing this definition for the *ʿaṣr*, although it is precisely this definition which underlies and inspired the standard definition in terms of the shadow increase that was used from the 9th century onwards. Certainly our author is not using those "new" definitions, because in Ch. 7 he proposes finding the shadows at the prayer-times from the corresponding altitudes.[5] An early work of al-Khwārizmī is a table displaying the shadows to one digit (base 12) at the two prayer-times for the latitude of Baghdad (33°) and each 6° of solar longitude. Each set of values was independently computed, showing that he was not using the "new" definitions.[6]

Ch. 5: The horizontal and vertical shadows, s and s′, for a gnomon length n = 12 when the solar altitude is h are related by:

$$s \times s' = n \cot h \times n \tan h = n^2 = 144.$$

In the Latin tradition a distinction is made between solar altitudes less than and greater than 45°. On shadow scales see **App. B.**

Ch. 7: The fact that the shadow-lengths need to be calculated confirms my restoration of Ch. 4.

Ch. 8: The two most common values for the length of the gnomon in Islamic astronomy from the 8th century onwards were 12 digits and 7 feet, others being $6^1/_2$ and $6^2/_3$.[7] See further **App. B**.

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[2] Ḥabash uses *shaẓiyya* and *majrā* in his treatise on the universal horary dial for timekeeping by the stars to describe first the movable cursor and then the hollowed groove in which it fits on a diametrical rule: see Charette & Schmidl, "Ḥabash's Universal Plate", pp. 135-136.

[3] See the article "Madjarra" by Paul Kunitzsch in *EI*$_2$.

[4] The same term in the Paris manuscript was rendered *mujerrih* in Sédillot-*fils*, *Mémoire*, pp. 104-105. See also Schmalzl, *Geschichte des Quadranten*, pp. 124-126.

[5] Using the new definitions in terms of shadow increases, the shadows would be given, and one would need to calculate the altitudes.

[6] See further King, "al-Khwārizmī", pp. 7-9; **II-3.1**; and **IV-4.5**.

The apparent divergence between these definitions—nowhere more apparent than on medieval sundials or astrolabe plates showing both the seasonal hours and the times of the *ẓuhr* and *ʿaṣr* prayers—is the result of the approximate nature of the Indian formula that was used to relate the time of day to shadow increases.

[7] See Kennedy, *al-Bīrūnī on Shadows*, I, pp. 68-79, and II, pp. 25-31; *idem et al.*, *Studies*, pp. 23-25; and **III-1.2**.

Ch. 9: We note the mention of latitude 33°. This is an early value for Baghdad used by al-Khwārizmī,[8] but it was still used in the 10th century: thus, for example, it is found on the astrolabes of Ḥāmid ibn ʿAlī al-Wāsiṭī (see **Figs. 10a** and **XIIIc-8.1**) and the celebrated astronomer Ḥāmid ibn Khiḍr al-Khujandī (see **Figs. XIIIc-9b** and **i**).[9] Better values had been determined already in the early 9th century. The value 33;9° for the latitude of Baghdad is also associated with al-Khwārizmī, although this may be result from a scribal error for the better value 33;21°, which, however, is elsewhere attested first in the 10th century.[10]

Ch. 10: Perhaps the copyist in Meshed thought that a quadrant with a cursor set for latitude 33° was not worth copying. Or maybe it was already missing from his original (for the same reason).

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[8] King, "al-Khwārizmī", p. 2. See also Kennedy & Kennedy, *Islamic Geographical Coordinates*, p. 55..

[9] #111—private collection—described in detail in King, "Kuwait Astrolabes", pp. 80, 82-89 (no. 2), also illustrated in King, *Mecca-Centred World-Maps*, pp. 18-19. See now **XIIIc-9**.

[10] See further Kennedy & Kennedy, *Islamic Geographical Coordinates*, pp. 55-56; King, "Earliest Muslim Geodetic Measurements", pp. 226-227; and *idem*, "Geography of Astrolabes", pp. 13-14, now in **XVI-4**.

APPENDIX B: ON SHADOW SCALES

No shadow scales are known from Greek astrolabes or Greek texts on the astrolabe.[1] Greek astrolabes, and with them the earliest Islamic astrolabes, bore no more than a single altitude scale and an alidade on the back (see **XIIIa-4**).[2] In a treatise by the early-9th-century Baghdad astronomer Abū Jaʿfar al-Khwārizmī on the construction of the astrolabe, a simple, single shadow-scale is described (see **Fig. B1**)[3], and such a scale is found on a 9th- or early-10th-century astrolabe by Muḥammad ibn Shaddād (al-Baladī) (see **Fig. B2**),[4] and also on a 16th-century
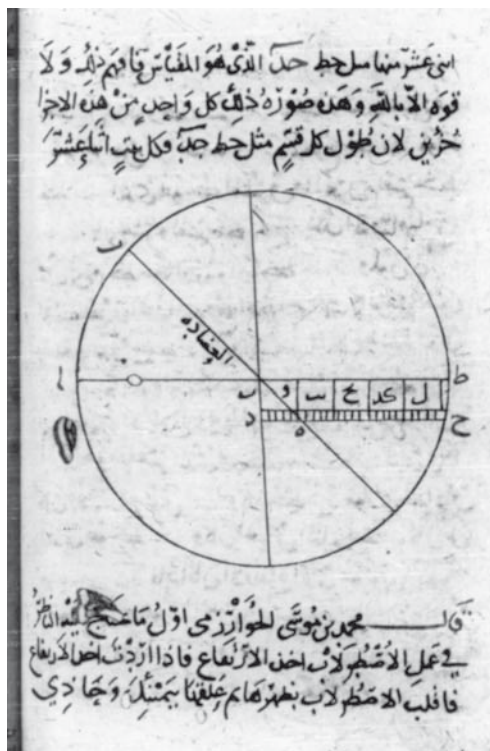
Fig. B1: The shadow scale to base 7 illustrated in al-Khwārizmī's treatise on the construction of the astrolabe. [From MS Berlin Ahlwardt 5793, fol. 81v, courtesy of the Deutsche Staatsbibliothek (Preußischer Kulturbesitz).]
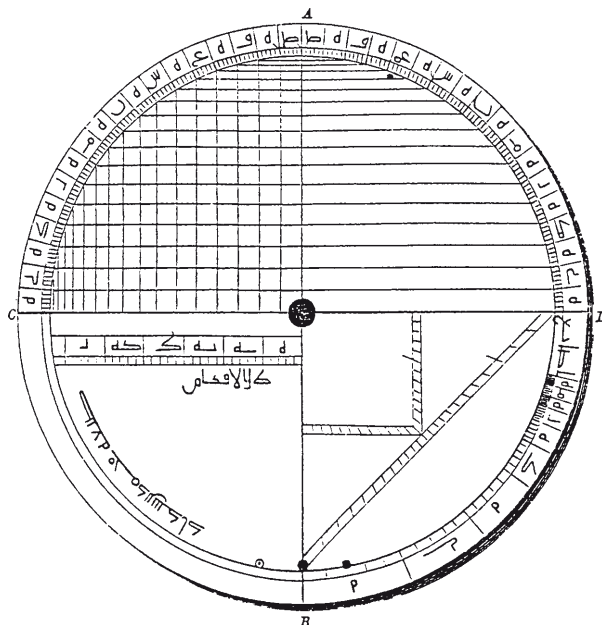
Fig. B2: On the back of this astrolabe from 9th- or early-10th-century Baghdad by Muḥammad ibn Shaddād al-Baladī (#1179) there are four different shadow scales. In the lower left quadrant we see the simple horizontal scale proposed by al-Khwārizmī, here to base 7 (*aqdām*, feet), and in the lower right quadrant a shadow square and a diagonal shadow scale (both without arguments), as well as a scale on the outer rim, all three to base 12 (*aṣābiʿ*, digits). [From Dorn, "Drei arabische Instrumente", p. 116.]

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[1] The quadruple shadow square on this sole surviving Byzantine astrolabe from the year 1062 (#2—Brescia, Museo dell'Età Cristiana, inv. no. 36—discussed and illustrated in Gunther, *Astrolabes*, I, pp. 104-108 (no. 2), after a 1926 study by O. M. Dalton) is a later addition.
is a later addition. The inclusion of such an absurd shadow square, so ungainly and over-sized that its corners interfere with the original inscriptions around the rim, reflects poorly on the person who added these markings.

[2] See also Stautz, "Früheste Formgebung der Astrolabien", p. 320.

[3] Omitted from King, "al-Khwārizmī". See now Charette & Schmidl, "al-Khwārizmī on Instruments", pp. 161 and 165-166.

[4] #1179—present location unknown, in the 19th century it was in Berlin in the possession of Dr. Wetzstein—published in Dorn, "Drei arabische Instrumente", pp. 115-118. See now **XIIIc-4**.

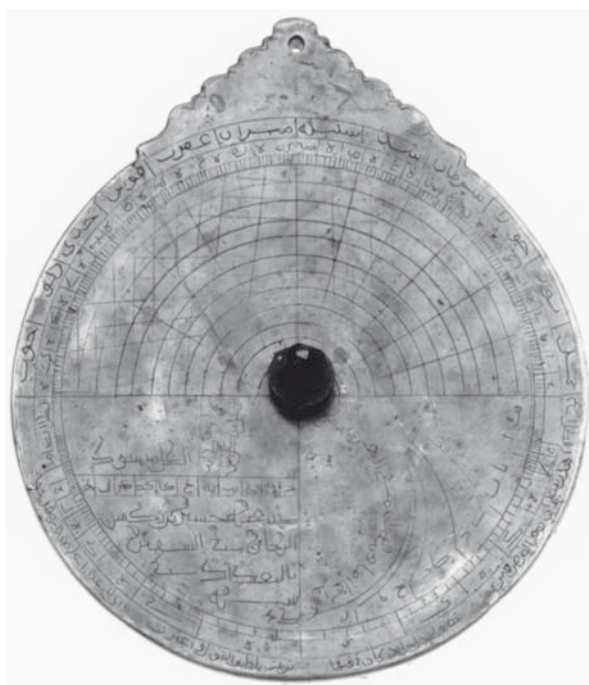



Fig. B3: A similar scale to base 12 labelled *al-ẓill al-mabsūṭ* with a vertical scale of 12 units *al-ẓill [al-]mankūs* at 12 units on the horizontal scale found on the back of a crudely-fashioned astrolabe apparently from Northern al-ʿIrāq and dating from the early 16th century (#4131). [Present location unknown; photo courtesy of Christie's of London.]

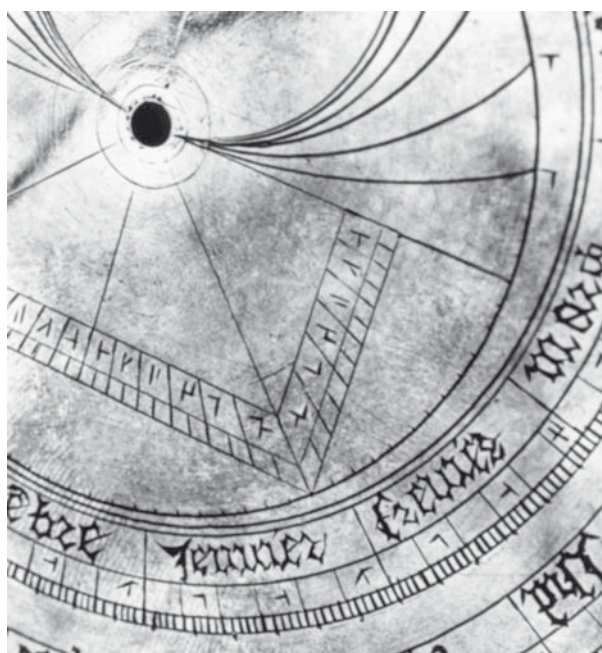
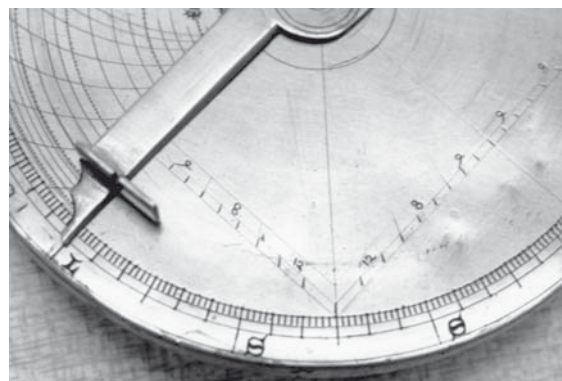
Fig. B4: The back of the astrolabe by Shams al-Dīn Muḥammad Ṣaffār dated 911 H [= 1505/06] (#2505), showing the two shadow squares to two different bases. [Courtesy of the Museum of the History of Science, Oxford.]

a

b

Fig. B5a-b: The defective shadow scales on two 14th-century astrolabes from Northern France. The first is from Picardy and has numbers written in a special monastic notation (#202). The second is of uncertain provenance and is fitted with a luni-solar gear mechanism (#198). On both the divisions on the shadow scales have been constructed by joining the centre to equal divisions of the outer scale. [Credits: a—private collection, photo by the author, courtesy of the owner; b—photo by Gerard L'E. Turner, courtesy of The Science Museum, London.]

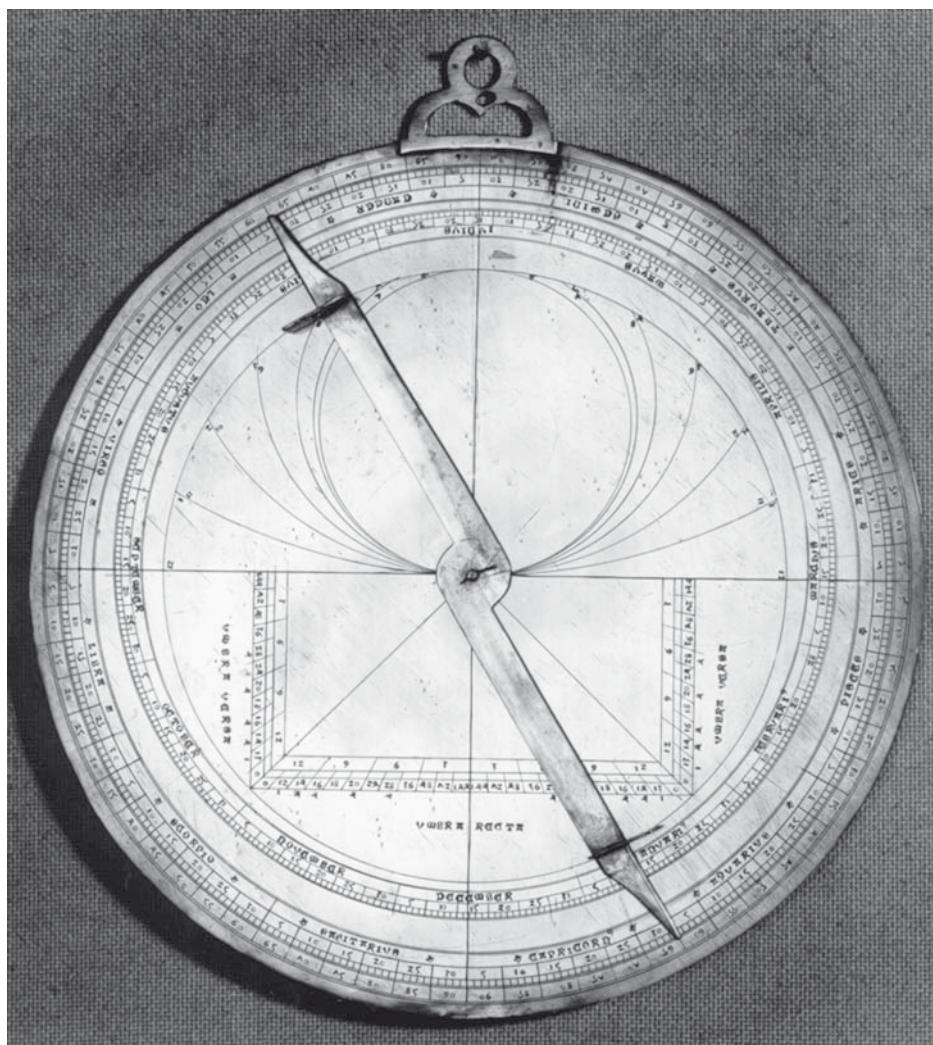



Fig. B6: The shadow scales on the back of a Southern German astrolabic plate dated 1468 (#550). [Courtesy of the Germanisches Nationalmuseum, Nuremberg.]

astrolabe from N. al-ʿIrāq (**Fig. B3**)[5] but not on any other known pieces. In the contemporaneous treatise on the universal horary quadrant with movable or fixed cursor discussed in the main text of this study a double shadow-scale (that is, a single shadow square) is included with the markings. On various astrolabes from 10th-century Baghdad[6] we find precisely such a shadow

[5] #4131—signed by one Ḥusayn ibn B-k-s (?) al-Raḥāqī and dated 913 H [= 1507/08]—present location unknown—see *Christie's (London) 24.09.1992 Catalogue*, pp. 36-37 (lot 112), *Sotheby's (London) 22.04.1999 Catalogue*, p. 46 (lot 72), and King, *Mecca-Centred World-Maps*, p. 354, n. 103.

[6] See now **XIIIc-4** and **8.1**.

Fig. B7: The tables of the cotangent function on the back of a Maghribī astrolabic plate datable *ca*. 1300 (the calendrical scale shows the equinox at March 14) (#4303). The instrument is also remarkable for the simplified rete: see **Fig. X-4.1.5**. [Photo from the archives of the late Alain Brieux, courtesy of Dominque Brieux, object in The Victoria and Albert Museum, London.]

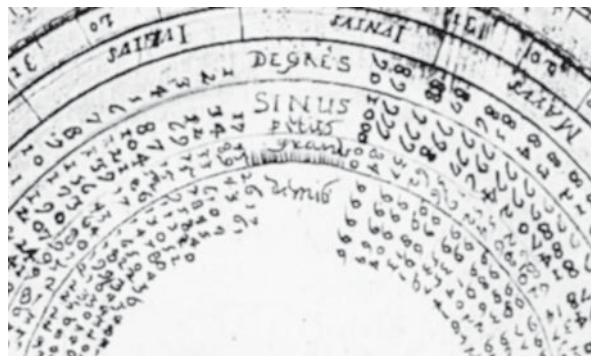
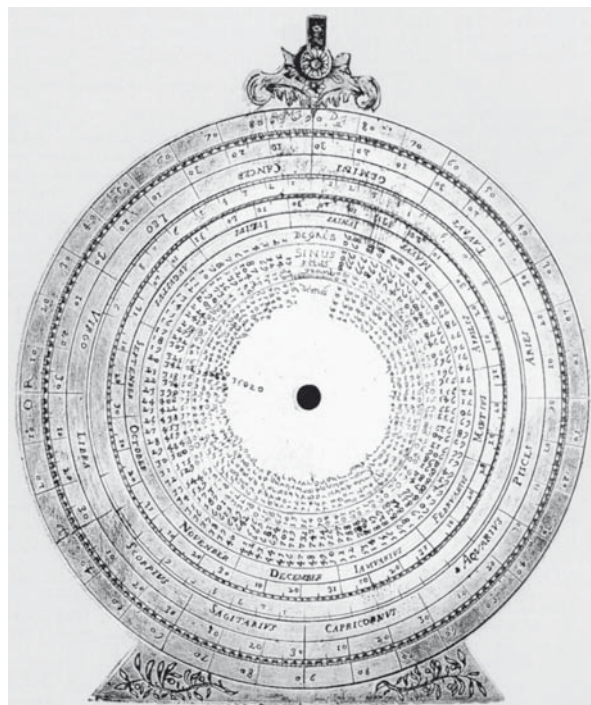



Fig. B8: The sine table on the back of an astrolabe (#634) made in Lyon *ca*. 1610. On the accuracy of the entries see King, "Schweinfurt Instruments", pp. 378-380. [Photo courtesy of the Stadtarchiv, Schweinfurt.]

square or double shadow-scale in the form found on most later astrolabes and also on the medieval English *navicula* (**XIIb-2**).[7] On the astrolabe of al-Baladī (**Fig. B2**) we find in the lower right quadrant a single shadow square within a diagonal scale in addition to the al-Khwārizmī-type scale in the lower right quadrant mentioned above; in addition there is a fourth scale on the rim of the lower right quadrant. The mid-9th-century Baghdad astronomer al-Farghānī in his influential treatise on the construction of the astrolabe (unpublished!) also prescribed and illustrated the simple kind of scale proposed by al-Khwārizmī (and no other).[8] These different kinds of shadow scales attest to an avid interest in shadows amongst contemporaneous Muslim astronomers; this interest was in part aroused by the newly-devised definitions of the times of the *ẓuhr* and *ʿaṣr* prayers in terms of shadow increases (**IV**).

On Islamic shadow squares (Arabic *murabbaʿ al-ẓill*) the horizontal shadow is generally labelled *al-ẓill al-mabsūṭ*, lit. "the shadow which is stretched out", and the vertical one *al-ẓill al-mankūs* or *al-maʿkūs*, both meaning "the reversed shadow".[9] In Latin these became *umbra recta* and *umbra versa*, with occasional variations (see **Figs. XIIb-10d** and **XIIIa-9.1a**). Very rarely the square of the base or gnomon length will be engraved by the appropriate scales (see below): this is useful for converting horizontal and vertical shadows 144 (see Ch. 5 in **App. A**).

The standard shadow square, single or double, became a common feature on Islamic astrolabes from the 10th to the 19th century, and on European astrolabes from the 10th century to the Renaissance. On Islamic pieces one side of the double square often serves base 12 (*iṣbaʿ*, pl. *aṣābiʿ*, digits) and the other side 7 (*qadam*, pl. *aqdām*, "feet"). A particularly interesting example is an astrolabe made by Muḥammad ibn Abi 'l-Qāsim al-Iṣfahānī in 496 H [= 1102/03] (**Fig. B4**): this bears a double shadow-square for digits on the left and feet on the right. The squares are labelled *ẓill al-aṣābiʿ q-m-d*, "shadow in digits, (square of the base) 144", and *ẓill al-aqdām m-b y-h*, "shadow in feet, (square of the base) 42;15", respectively, and the scales are indeed divided into 12 and $6^1/_2$, respectively.[10] The same use of two different bases is also attested on the shadow scales on the rims of many Islamic astrolabes, but it is the exceptions to the rule that are of most historical interest. A single shadow square is often an indication that we are dealing with an *early* Islamic or *early* European instrument.[11]

A most unusual and rather ingenious shadow scale is found together with a universal horary quadrant on the back of an English astrolabe from *ca*. 1300 (see **Fig. 7b**).[12] The scale forms a crescent with the half circumferential scale for the altitude. The horary quadrant has its centre

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[7] See also **XIIb-9a-c** on the combination of the shadow square with a universal horary quadrant.

[8] MSS Berlin Ahlwardt 5791, fols. 64r-65r, and 5790, fols. 51v-52v. This section is followed by another presenting the *ẓill al-ʿūd*, which is none other than the curve for the *ʿaṣr* on the plate of an astrolabe.

[9] Kunitzsch, "Fachausdrücke der Astrolabliteratur", pp. 562-563.

[10] #122—Florence, Museo della Storia della Scienza, inv. no. 1105—see Gunther, *Astrolabes*, p. 263 (no. 122), and now **XIIIb-11**.

[11] For examples of each kind see:

#4024—illustrations found in an 11th-century Latin manuscript of a 10th- or 11th-century Andalusī astrolabe with Arabic inscriptions including a signature by Khalaf ibn Muʿādh: see Kunitzsch, "10th-Century Andalusī Astrolabe", and **Fig. XIIIa-9.2b**.

#3042—the earliest European astrolabe, from 10th-century Catalonia: see **Fig. XIIIa-9.1a**.

[12] #296—see n. 7:7.

at the top of the upper semicircle of the circumference, at which the thread and bob are attached. The lower semicircle is divided from left to right into 90° and the divisions are marked according to the chords extending from the centre of the horary quadrant. The shadow scale runs from 0 to 12 for altitudes 0°-45° and 12 to 0 for altitudes 45°-90°, the two halves being labelled "•. *maior*" and "•. *minor*", where •, which looks like a Greek γ, is possibly a "U" or "u" for *umbra*. It seems reasonable to suspect Islamic inspiration behind this ingenious device which is unknown from the available Islamic sources.

The construction of the scales on shadow squares is so simple that it is surprising to find that on two 14th-century Northern French astrolabes they are incorrectly constructed (with unequal divisions) by joining the centre to equal divisions of the circumferential scale (**Figs. B5a-b**).[13] On the scales of a double shadow square on the back of a Southern German astrolabic plate dated 1468 an additional set of numbers attempts to provide the quotients derived by dividing the numbers on one of the scales into 144 (**Fig. B6**). These are given in the form n,r where n is the integral quotient and r is the remainder; several mistakes indicate that the operation was alas beyond the skills of the maker.[14] On a compendium by Humphrey Cole dated 1568 we find a a *quadrans astronomicus*, which is simply a quadrant with a scale 0°-90°, and *quadrans geometricus* adjacent to it and concentric with it, consisting two half scales showing the *umbra versa* from 0 to 12 (for altitudes 0°-45°) and the *umbra recta* from 12 to 0 (for altitudes 45°-90°).[15] Any 9th-century Muslim astronomer worth his salt could have understood this and could have come up more useful.

Finally, we mention an unsigned Maghribi astrolabic plate from *ca*. 1300 for latitude 34° [Meknes] (#4303), which bears a circular scale on the back displaying cotangents to bases 12 and 6;40 for each degree of argument, with values to two digits (see **Fig. B7**).[16] This would have been more than any user would have needed, and we may compare an unsigned astrolabe from Lyon, *ca*. 1610 (#634), on which is engraved a table of the sine function to base 10^5 with values for each 0;30°, which are not as accurate as the engraver supposed (see **Fig. B8**).[17]

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[13] #202—private collection—see Gunther, *Astrolabes*, II, p. 349 (no. 202), and King, *Ciphers of the Monks*, pp. 131-151 and 406-419.
#198—London, Science Museum, inv. no. 1880.32—see Gunther, *Astrolabes*, II, p. 347 (no. 198).
On the shadow squares on these two pieces see King, *Ciphers of the Monks*, pp. 416-417.

[14] #550—Nuremberg, Germanisches Nationalmuseum, inv. no. WI 5—see Gunther, *Astrolabes*, I, p. 280 (no. 137, incorrectly associated with Regiomontanus); and *Nuremberg GNM 1992-93 Catalogue*, pp. 589-592 (no. 1.77), esp. p. 591a.

[15] Turner, *Elizabethan Instrument Makers*, pp. 112-113 *ad* no. 8.

[16] #4303—London, Victoria & Albert Museum, inv. no. I.M. 406-1924. This instrument was not recorded by Derek Price because in the 1950s the Museum did not have a clear idea of its holdings of astronomical instruments. Half a century later, this problem has not yet been resolved.

[17] #634—see my description in *Schweinfurt 1993 Exhibition Catalogue*, pp. 374-381 (no. 181). For another instrument (#532) by the same maker, misidentified as South German, see *Chicago AP Catalogue*, A, pp. 100-101 (no. 21).

> "What is remarkable about this type of dial, when compared to all known designs of fixed dial from antiquity, is that its design embodies an approximation." M. T. Wright, "Greek and Roman Approximate Sundials" (2000), p. 177. [In fact, this is not at all surprising; what is remarkable about these dials is that they are universal.]

A variety of approximate universal equatorial sundial designated προς παν κλιμα, "for all climates", was known in Antiquity, and its use continued throughout the Middle Ages in both the Near East and Europe in a modified form. In its original form it consisted of an alidade attached to a circular frame, a single sight at one end casting a shadow on a scale curved away from the base of the alidade. Several examples of such devices survive from the Graeco-Roman and Byzantine periods.[1]
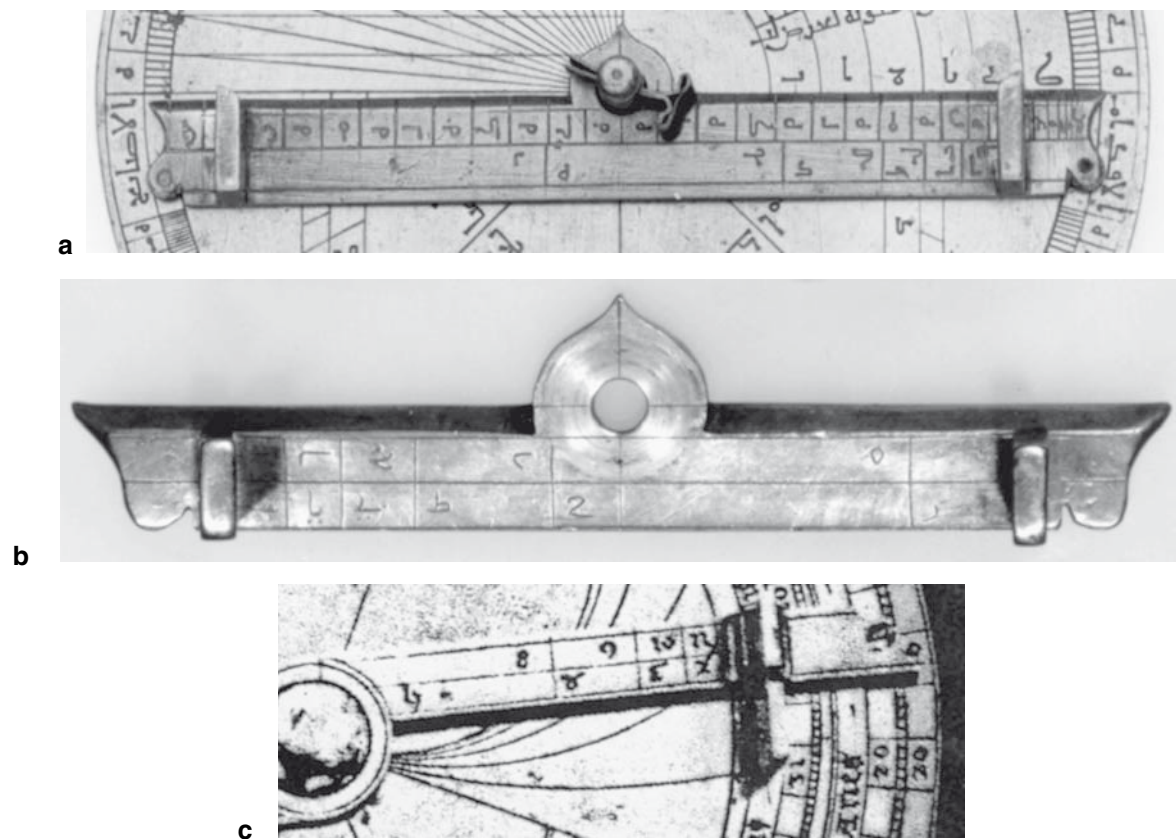
Fig. C1a-c: Three alidades with universal sundials, from Isfahan *ca*. 1100 (#122), the Yemen *ca*. 1295 (#109), and the workshop of Jean Fusoris in Paris *ca*. 1400 (#568). [Credits: (a) Courtesy of the Museo di Storia della Scienza, Florence (a), the Metropolitan Museum of Art, New York (b), and the Jagiellonian Museum, Cracow (c).]

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[1] On the antique variety see Drecker, *Theorie der Sonnenuhren*, pp. 58-66; Price, "Portable Sundials in Antiquity", pp. 253, 256, *etc.*; Buchner, "Antike Reiseuhren"; and Field & Wright, "Gears from the Byzantines", pp. 126-127. In Wright, "Greek and Roman Approximate Sundials", too much emphasis is placed on the underlying approximation and not enough on the universality of the instrument.

In its medieval form the device was reduced to a series of markings representing the seasonal hours on the alidade of an astrolabe, one sight being used as a gnomon. A very limited number of early Islamic, medieval European, and later Islamic astrolabes bear alidades with these markings: see **Fig. C1** for some examples.[2] As far as I am aware, the continuity of the tradition is not generally known.[3] Sometimes the purpose of these markings has been misunderstood by modern researchers.[4]

To use the device one should suspend the astrolabe in the plane of the meridian and point the alidade towards the meridian position of the sun. Then, regardless of the local latitude, at each seasonal hour the shadow of the upper sight will fall on the appropriate mark on the alidade, except at midday when it falls on the other sight and at sunrise or sunset when there is no shadow. It is supposed that the "altitude" of the sun in the plane of the day-circle decreases from 90° by 15° each hour. Given its crudity the device is surprisingly accurate.[5] Clearly the underlying principle is not directly related to the standard approximate formula, although Abū ʿAlī al-Marrākushī does mention it as a special case.[6]

al-Bīrūnī (*fl.* Central Asia *ca.* 1025) reported that Ḥabash al-Ḥāsib, in some work of his now lost, had discussed such alidade markings, and that he had presented a table to facilitate engraving them: the table simply displays values of $\mathrm{Tan}_{12}(15i)°$ for $i = 1, 2, \ldots, 6$).[7] al-Bīrūnī also stated that the device, which he called *sāq al-jarāda*, "the locust's leg",[8] was most commonly used on instruments displaying the phases of the moon (*ḥuqq al-qamar*).[9] He further described a related scale in the form of half a cylindrical ring which could be attached to the alidade: it had the advantage of having a uniform scale and all the drawbacks of the more common *sāq al-jarāda*.[10]

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[2] #116—Berlin, Staatsbibliothek, inv. no. Sprenger 2050—signed by Muḥammad ibn al-Ṣaffār and dated 420 H [= 1029/30]—see the detailed study in Woepcke, "Arabisches Astrolab", and the summary in Gunther, *Astrolabes*, I, pp. 251-252 (no. 116).

#109—New York, Metropolitan Museum of Art, inv. no. 91.1.535—signed by the Yemeni sultan ʿUmar ibn Yūsuf and dated 690 H [= 1291]—see Gunther, *op. cit.*, I, p. 243 (no. 109), and the detailed description in King, "Yemeni Astrolabe", now in **XIVa**; see also n. C:4 below.

#568—Cracow, Jagiellonian Museum, inv. no. ? (formerly at Wroclaw University)—a typical astrolabe of the Fusoris atelier *ca.* 1425—unpublished.

[3] It was pointed out already in *Washington NMAH Catalogue*, p. 59, where, however, the authors mistakenly claim that the markings should be used in conjunction with an astrolabe plate.

[4] The supposed non-functionality of the markings on the alidade of the sole surviving astrolabe by the Yemeni Sultan al-Ashraf (see **Fig. C1b**) claimed in King, "Yemeni Astrolabe", p. 107, is nonsense. Since I did not understand the markings I claimed the alidade could not be used and therefore that it could not be original. Several parallels come to mind.

[5] Drecker, *Theorie der Sonnenuhren*, pp. 64-66.

[6] See **XI-2.2**.

[7] On al-Bīrūnī see the *DSB* article by E. S. Kennedy. For this passage see *idem*, *al-Bīrūnī on Shadows*, I, pp. 238-241, and II, pp. 149-151.

Ḥabash also put a tangent scale for terrestrial latitude on his universal horary dial for the stars. The universal horary dial for the sun on the *navicula* also has a tangent scale for the latitude.

[8] Unfortunately this name was also used in technical Arabic for latitude-specific and universal vertical sundials: see Charette, *Mamluk Instrumentation*, pp. 145-150 and 174-176.

[9] The dubious reading noted in Kennedy, *al-Bīrūnī on Shadows*, II, p. 241, n. 1, is *ḥuqq al-qamar*.

[10] *Ibid.*, I, pp. 241-242, and II, pp. 151-152.

The universal sundial was also known in medieval Europe. The markings are found on a very few medieval European astrolabes, including one from the atelier of Jean Fusoris (see **Fig. C1c**).[11] The use of such markings is recorded, for example, already in the Latin treatise on the astrolabe falsely associated with Messahalla (Gunther's translation):[12]

> *Si per allidadam horariam vis scire horam diei naturalem, pone allidadam super altitudinem medie diei illius in dorso astrolabii suspensi; et verte dorsum ad solem tam diu donec umbra uniuscuiusque anguli superioris pinnule cadat in allidada, quelibet in directo sui lateris; et ubi occiderit in divisionibus erit hora quesita.* // If you wish to know the natural (i.e. seasonal) hour of the day by the horary alidade, set the alidade on the (sun's) altitude at midday on the back of the astrolabe (whilst) suspended, turn the back to the sun until the shadow of each corner of the upper pinnule falls on the alidade anywhere in line with its side. Then the division on which it falls will be the desired hour.

It is also found in the treatise associated with Hermannus Contractus (early 11th century):[13]

> *Quando vis scire in dorso astrolapsus [!] hora ... ... dum sol pervenerit ad ipsa signa in Alhidada, scias sic horas certas usque ad 6; post 6, retorna descendendo usque ad occasum ... ,*

adding that if you want to do it properly you should use the front of the astrolabe. Jean Fusoris wrote about these markings in the same chapter in which he treated the universal horary quadrant:[14]

> *... pour savoir les heures inegalles en tous climas par autre maniere ... . Soit mise l'alidade sur la haulteur du mydi en dos de l'astralabe vers le soleil jusques a tant que l'ombre de la pynnule qui est vers le soleil chiée [leg. chie ?] sur l'alidade droictement sur son costé, et l'ombre vousmonstrera les heures inesgalles.* // ... to find the seasonal hours in any latitude by another procedure ... . Let the alidade be placed at the midday altitude on the back of the astrolabe so that the shadow of the (upper) pinnule towards the sun fits directly along (the scale on) the side of the alidade: then the shadow will show you the seasonal hours (throughout the day).

Since the alidade is the first piece of an astrolabe to get broken and removed, sometimes to be replaced by an inferior substitute, and since it is often the last piece to get photographed, if at all, a survey of surviving alidades in quest of such markings would be frought with difficulty.

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[11] See n. C:2 *ad* #568.

[12] For the text of Maslama al-Majrīṭī (shown by Paul Kunitzsch to be falsely attributed to Māshā'allāh) see Gunther, *Early Science in Oxford*, V, pp. 220 and 174 (also mentioned in Morley, *Astrolabe of Shāh Ḥusayn*, p. 21, and quoted in *Washington NMAH Catalogue*, p. 59). See also Gunther, *op. cit.*, V, p. 146.

[13] For the text of Hermanus Contractus see Gunther, *Astrolabes*, II, p. 418 (not in Drecker, "Hermannus Contractus über das Astrolab").

[14] Poulle, *Fusoris*, p. 116.

#2 Byzantine astrolabe dated 1062 — Brescia, Museo dell'Età Cristiana, inv. no. 36 — published in Dalton, "Byzantine Astrolabe", summarized in Gunther, *Astrolabes*, I, pp. 104-108 (no. 2), and now **XIIIa-4** B:1

#3 Astrolabe by Aḥmad and Muḥammad, sons of Ibrāhīm al-Iṣfahānī, dated 374 H [= 984/85] — Oxford, Museum of the History of Science, inv. no. ICC 3 — see Gunther, *Astrolabes*, I, pp. 114-116 (no. 3), and now **XIIIc-10** 15:2

#12 Astrolabe by Mukhliṣ Shirwānī dated 910 H [= 1504/05] — Cairo, Museum of Islamic Art, inv. no. 15360 — see now the detailed description in **XIVe-1** 6, Fig. 6c

#100 Astrolabe by Ḥāmid ibn ʿAlī (al-Wāsiṭī) dated 343 H [= 954/55] — stolen from the Museo Nazionale in Palermo some 50 years ago — published in Mortillaro, "Astrolabio arabo", and now **XIIIc-8.1** 10, Fig. 10a, A1, comm. ch. 9

#109 Astrolabe signed by the Yemeni sultan al-Ashraf ʿUmar ibn Yūsuf and dated 690 H — New York, Metropolitan Museum of Art, inv. no. 91.1.535 — see Gunther, *Astrolabes*, I, p. 243 (no. 109), and the detailed description in King, "Yemeni Astrolabe", and now **XIVa** C:2 and 4, Fig. C1b

#111 Astrolabe by Ḥāmid ibn Khiḍr al-Khujandī dated 374 H [= 984/85] — private collection — see Gunther, *Astrolabes*, I, p. 245 (no. 111); and the detailed description in King, "Kuwait Astrolabes", pp. 80, 82, 83-89, and now **XIIIc-9** A:9, comm. ch. 9

#116 Astrolabe by Muḥammad ibn al-Ṣaffār dated 420 H [= 1029] — Berlin, Deutsche Staatsbibliothek, Preußischer Kulturbesitz, Orientabteilung, inv. no. 6567 (Sprenger 2050) — see the detailed study in Woepcke, "Arabisches Astrolab", and the summary in Gunther, *Astrolabes*, I, pp. 251-252 (no. 116) C:2, Fig. C1a

#122 Astrolabe by Muḥammad ibn Abi 'l-Qāsim al-Iṣfahānī dated 496 H [= 1102/03] — Florence, Museo di Storia della Scienza, inv. no. 1105 — see Gunther, *Astrolabes*, I, p. 263 (no. 122), and now **XIIIc-11** B:10

#123 Astrolabe by Ibrāhīm ibn Saʿīd al-Sahlī, dated Valencia, 463 H [= 1070/71] — Osservatorio di Roma — unpublished; see Gunther, *Astrolabes*, I, p. 263 (no. 123) 6:2

#142 Astrolabic plate by Ibn al-Shāṭir dated 733 H — Paris, Bibliothèque nationale de France, Département des cartes et plans, inv. no. ? — unpublished, listed in Mayer, Islamic Astrolabists, pp. 40-41; see Gunther, *Astrolabes*, I, p. 287 (no. 142) 8:12

#193 Unsigned, undated astrolabe attributable to the atelier of Jean Fusoris, Paris, *ca.* 1425 — Chicago, Adler Planetarium, inv. no W-264 — see *Chicago AP Catalogue*, I, pp. 46-48 (no. 3) 12:2, Fig. 12a

#198 14th-century Northern French geared astrolabe — London, Science Museum, inv. no. 1880.32 — see Gunther, *Astrolabes*, II, p. 347 (no. 198), and King, *Ciphers of the Monks*, pp. 398-399 and 402-403, Figs. 6a-b, also pp. 416-417 B:13, Figs. B5b

#202 14th-century Picard astrolabe marked with monastic ciphers — private collection — see Gunther, *Astrolabes*, II, p. 349 (no. 202), and King, *Ciphers of the Monks*, pp. 131-151 and 406-419, esp. 416-417 B:13, Figs. B5a

#256 Astrolabe in the Regiomontanus tradition with additional 16th-century inscriptions — present location unknown, formerly in a private collection in Paris — Gunther, *Astrolabes*, II, p. 434 (no. 256); King & G. Turner, "Regiomontanus' Astrolabe", p. 189 and figs. 18-19; and G. Turner in *Christie's London 08.04.1998 Catalogue*, pp. 70-73 (lot 49) 1 (quote)

#296 14th-century English astrolabe with a universal horary quadrant on the back — Oxford, Oriel College — see Gunther, *Astrolabes*, II, p. 473 (no. 296) Fig. 7b; B:12

#337 The "Thornoe" astrolabe, French, 14th century — Greenwich, National Maritime Museum, inv. no. A34/36-28C — description forthcoming in *Greenwich Astrolabe Catalogue* 12:4, Fig. 12d

#532 Unsigned astrolabe from Lyon, datable *ca.* 1610 — Chicago, Adler Planetarium, inv. no. M-32 — see *Chicago AP Catalogue*, A, pp. 100-101 (no. 21, misidentified as South German) B:17

#550 Unsigned S. German astrolabic plate dated 1468 — Nuremberg, Germanisches Nationalmuseum, inv. no. WI 5 — see Gunther, *Astrolabes*, I, p. 280 (no. 137, incorrectly associated with Regiomontanus); and *Nuremberg GNM 1992-93 Catalogue*, pp. 589-592 (no. 1.77), esp. p. 591a B:14, Fig. B6

#568 Undated, unsigned astrolabe from the school of Jean Fusoris — Cracow, Jagiellonian Museum, inv. no. ? (formerly at Wroclaw University) — unpublished C:2 and 11, Fig. C1c

#634 Unsigned astrolabe from Lyon, datable ca. 1610 — Schweinfurt, Stadtarchiv, inv. no. 2 — detailed description in *Schweinfurt* 1993 *Exhibition Catalogue*, pp. 374-381 (no. 181) B:17, Fig. B8

#1131 Astrolabic plate by Ibn al-Shāir dated 733 H — Cairo, Museum of Islamic Art, inv. no. 15362 (or 15363?) — unpublished; listed in Mayer, *Islamic Astrolabists*, pp. 40-41 8:12

#1148 Astrolabe by Muḥammad ibn Fattūḥ al-Khamāʾirī dated 628 H — Cairo, Museum of Islamic Art, inv. no. 15371 — unpublished 15:2

#1179 10th-century astrolabe mater by Muḥammad ibn Shaddād (al-Baladī) — present location unknown, formerly (1864) in Berlin in the possession of Dr. Wetzstein — published in Dorn, "Drei arabische Instrumente", pp. 115-118, and now **XIIIc-4** B:4, Fig. B2

#2006 Undated medieval English astrolabe with zoomorphic representations on the rete — Washington, D.C., National Museum of American History, inv. no. 318198 — see Washington *NMAH Catalogue*, figs. 16 (p. 14), 20 (p. 23), and 28 (p. 46), and pp. 45-47 and 153-154 (no. 2006). 8:4

#2505 Astrolabe by Shams al-Dīn Muḥammad —affār dated 911 H [= 1505/06] — Oxford, Museum of the History of Science, inv. no. ? — see *Oxford MHS Billmeir Supplement Catalogue*, pp. 19-20 (no. 158) Fig. B4

#3000 Unsigned, undated late medieval astrolabe — Basle, Historisches Museum, inv. no. ? — unpublished 12:6, Fig. 12e

#3042 Unsigned 10th-century astrolabe from Catalonia — Paris, Institut du Monde Arabe, inv. no. AI 36-31— see Destombes, "Astrolabe carolingien", and various articles in Stevens *et al.*, The *Oldest Latin Astrolabe*, also **XIIIa-9** B:11

#4024 Illustrations of a 10th- or 11th-century Andalusī astrolabe with Arabic inscriptions and signed by Khalaf ibn Muʿādh, found in an 11th-century Latin manuscript — see Kunitzsch, "10th-Century Andalusī Astrolabe", and now **XIIIa-9** B:11

#4054 Astrolabe by Muḥammad ibn Fattūḥ al-Khamāʾirī of Seville dated 619 H [= 1223/24] — present location unknown; formerly in the Linton Collection — see *Linton Collection Catalogue*, pp. 171-173 (no. 221) 10:2

#4131 Astrolabe by Ḥusayn ibn B-k-s (?) al-Raḥāqī and dated 913 H [= 1507/08] — present location unknown — see *Christie's (London) 24.09.1992 Catalogue*, pp. 36-37 (lot 112), *Sotheby's (London) 22.04.1999 Catalogue*, p. 46 (lot 72), and King, *Mecca-Centred World-Maps*, p. 354, n. 103 B:5, Fig. B3

#4303 Unsigned Maghribi astrolabic plate datable ca. 1300 — London, Victoria & Albert Museum, inv. no. I.M. 406-1924 — unpublished B:16, Fig. B7

#4570 Signed Italian astrolabe dated 1558 — Museum of History of Science, Oxford, inv. no. 26, not listed in Price et al., *Astrolabe Checklist* — unpublished 14:2, Fig. 14b

#5021 Astrolabic quadrant for [Meknes] by Aḥmad ibn ʿAbd al-Raḥmān al-Dahmānī dated 854 H [= 1450/51] — Madrid, Museo Arqueológico Nacional, inv. no. 50856, electrotype copy in the Science Museum, London, inv. no. 1877-5 — see Mayer, *Islamic Astrolabists*, p. 34, and the bibliography there cited 11:2, Fig. 11a

#5501 Medieval *quadrans vetus* in wood, unsigned and undated — until recently in a private collection in Milan, present location unknown — unpublished Fig. 7c, 13:1

#5502 Medieval *quadrans vetus*, unsigned and undated — Oxford, Museum of the History of Science, inv. no. 52020 — illustrated in Poulle, *Instruments astronomiques*, 1969 edn., p. 19; see now Meliconi, "Oxford *Quadrans vetus*" on EPACT 7:1

#5503 Medieval *quadrans vetus*, unsigned and undated — Florence, Museo di Storia della Scienza, inv. no. 662 — illustrated in Poulle, *Instruments astronomiques*, 1983 edn., p. 10, and King, *Mecca-Centred World-Maps*, p. 356; see now A. J. Turner, "Florence *Quadrans vetus*" on EPACT Fig. 2c; 7:1

#5504 Medieval *quadrans vetus*, unsigned and undated — London, British Museum, inv. no. 1972 1-4 1 — see *London BM Catalogue*, p. 55 (no. 145) and pl. XX, and now Ackermann, "London BM *Quadrans vetus*" on EPACT 7:1

#5505 Medieval *quadrans vetus*, unsigned and undated — Vienna, Kunsthistorisches Museum, inv. no. ? — unpublished 7:2

#5506 Medieval *quadrans novus*, unsigned and undated — Oxford, Merton College — see Gunther, Science in Oxford, II, pp. 164-169; North, *Richard of Wallingford*, III, p. 134; and Dekker, "Quadrans novus", p. 20, etc. 8:3, Fig. 8a

#5507 Medieval *quadrans novus*, unsigned and undated — Washington, National Museum of American History, inv. no. 326975 — see Dekker, "*Quadrans novus*", pp. 16-17, etc. 8:3

#5508 Medieval *quadrans novus*, unsigned and undated — present location unknown — described by D. A. King and Elly Dekker in *Christie's London 02.03.19995 Catalogue*, p. 35 (lot 198) 8:3

#5509 Medieval *quadrans novus*, unsigned and undated — present location unknown — described in detail in Dekker, "*Quadrans novus*" 8:3

#5511 Medieval *quadrans novus*, unsigned and undated — Rouen, Musée des Antiquités de la Seine Maritime, inv. no. 919 — published in Anthiaume & Sottas, "*Quadrans novus*"; see also Dekker, "*Quadrans novus*", pp. 18-19, etc. 8:3

#5512 Medieval *quadrans novus*, unsigned and undated, datable to 1415 — Angers, Musée de Saint-Jean, inv. no. MA GF39 — unpublished, see Dekker, "*Quadrans novus*", p. 22, etc. 8:3

#5513 Medieval *quadrans novus*, unsigned and undated — Luneburg, Museum für das Fürstentum Lüneburg, inv. 122 — unpublished, see Dekker, "*Quadrans novus*", p. 21, etc. 8:3

#5515 German brass *quadrans vetus* on a square plate, dated 1523 — present location unknown, passed through Auktionshaus Hampel in Munich *ca.* 1995 — unpublished Fig. 7a

#5521 English horary quadrant dated 1398 — Dorchester, Dorchester Museum — see *London BM Catalogue*, pp. 55-56 ad no. 146, and pls. XVIIb and XVIIIb; and Ackermann & Cherry, "Three Medieval English Quadrants" 13:2

#5522 English horary quadrant dated 1399 — London BM, inv. no. 60 5-19 1 — see *ibid.*, pp. 55-56 (no. 146) and pls. XVIIa and XVIIIa; Ackermann & Cherry, "Three Medieval English Quadrants"; also G. Turner, "Whitwell's Addition to a 14th-Century Quadrant", and *idem*, *Elizabethan Instrument Makers*, no. 44 at pp. 190-191 13:2 and 3

#5523 Undated horary quadrant, early 15th century (?) — London BM, inv. no. 56 6-27 155 — see *London BM Catalogue*, p. 56 (no. 147); and Ackermann & Cherry, "Three Medieval English Quadrants" 13:2

#8501 Astrolabic plate with universal horary dial, signed by Roger Brechte and dated 1527 — Oxford, Museum of the History of Science (formerly St. John's College), inventory no. 26323 — see Gunther, *Early Science in Oxford*, II, pp. 135-140 (no. 56); Meliconi, "Brechte Plate", on EPACT; and now XIIb-11 8, 8:8

#8532 *navicula*, unsigned and undated, German-type design — Florence, Museo di Storia della Scienza, inv. no. 3163 — previously unpublished, see now XIIb-10 7:6

Manuscripts

Berlin DSB Ahlwardt 5790, 5791: B:8; 5793: Fig. B1
Cairo ENL DM 969,4: 2, 2:1, Fig. 2a, A (text); DM 969+970: 2:1; MR 40,2: Fig. 6.1; M 155,3: 5:2
Istanbul Haci Mahmud Efendi 5713: 11:1; Topkapı A.III 3343: Fig. 5a
Meshed Shrine Library 392+393: Fig. 2a (caption)
For manuscripts on the *quadrantes veteres* and *novi* and the European textual tradition see also the bibliographical citations in Archinard, "Unequal Hour Diagram", and Knorr, "*Quadrans Vetus*", p. 23. For those on universal horary dials see **XIIb-A**.

Part XIIb

On universal horary dials for timekeeping by the sun and stars

To the memory of Derek de Solla Price

DEDICATION, ACKNOWLEDGEMENTS AND NOTES ON THIS VERSION

This study is dedicated to the memory of Derek de Solla Price (1922-1983), who, in addition to his better-known contributions to the history of science and to scientometrics,* was one of the few historians of science in the 20th century to recognize the importance of astronomical instruments as historical sources. The interested reader may consult the eloquent obituary by Gerard L'E. Turner in *Annals of Science* 41 (1984), pp. 105-107. Whilst Derek Price's ground-breaking researches on the Chaucer equatorium and the Antikythera machine are published in book form, various other works of his might not be so well known, and so I list them chronologically here:

- *The Equatorie of the Planetis edited from Peterhouse MS. 75.I* (with R. M. Wilson), Cambridge: Cambridge University Press, 1955.
- "An International Checklist of Astrolabes", *Archives internationales d'Histoire des sciences* 8 (1955), pp. 243-263, and pp. 363-381.
- "Fake Antique Scientific Instruments", in *Actes du VIIIe Congrès International d'Histoire des Sciences, Florence, 3-9 Sept., 1956*, pp. 380-394 (separatum paginated 1-15).
- "Precision Instruments to 1500", in Charles Singer *et al*., eds., *A History of Technology*, III, Oxford: Clarendon Press, 1957, pp. 582-619.
- "The First Scientific Instrument of the Renaissance", *Physis* 1 (1959), pp. 26-30. [On the astrolabe presented by Regiomontanus to Cardinal Bessarion, later deemed a fake, but more recently, thanks to the identification of other pieces from the same workshop, re-established as genuine.]
- "On the Origin of Clockwork, Perpetual Motion Devices and the Compass", *Contributions from the Museum of History and Technology*, United States National Museum, *Bulletin* 218 (1959), Paper 6, pp. 81-112.
- "The Little Ship of Venice, a Middle English Instrument Tract", *Journal of the History of Medicine and Allied Sciences* 15 (1960), pp. 399-407.
- "Medieval Water Clocks of the 14th Century in Fez, Morocco", *Proceedings of the Xth International Congress of History of Science, (Ithaca, 1962)*, pp. 599-602.
- "The Tower of the Winds", *National Geographic* 131:4 (April, 1967), pp. 586-596.
- "Portable Sundials in Antiquity, including an Account of a New Example from Aphrodisias", *Centaurus* 14 (1969), pp. 242-266.
- *A Computerized Checklist of Astrolabes* (with Sharon Gibbs and Janice A. Henderson), New Haven Conn.: Yale University, Department of History of Science and Medicine, 1973.
- "Gears from the Greeks—The Antikythera Mechanism: A Calendar Computer from *ca*. 80 B.C.", *Transactions of The American Philosophical Society*, N.S., 64:7 (1974), repr. in book form: New York, N.Y.: Science History Publications, 1975.

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* See www.garfield.library.upenn.edu/price/derekprice.html.

- *Science since Babylon—Enlarged Edition*, New Haven & London: Yale University Press, 1975. [Contains important articles on mechanical devices and scientific symbols.]
- "Philosophical Mechanism and Mechanical Philosophy—Some Notes toward a Philosophy of Scientific Instruments", *Annali dell'Istituto e Musei di Storia della Scienza di Firenze* 5:1 (1980), pp. 75-85.
- "Instruments of Reason. Centerpieces of Renaissance science have become objets d'art", *The Sciences* (New York Academy of Sciences), October 1981, pp. 15-17.
- "Instruments in the British Museum", *Journal for the History of Astronomy* 13 (1982), pp. 129-132. [An essay review of F. A. B. Ward, *A Catalogue of European Scientific Instruments in the Department of Medieval and Later Antiquities of the British Museum*, London: British Museum Publications, 1981.]

The interested reader will find a few more relevant writings listed in the extensive bibliography in Yagi & Badash & Beaver, "Derek J. de Solla Price" (1996), pp. 76-83, which came to my attention during second proofs.

It is a constant regret of mine that I never attended any lectures of Derek's on instruments whilst at Yale, where he and his young colleagues were deeply involved with the *Astrolabe Checklist*. For better and for worse, I was immersed in Islamic mathematical astronomy, but, no less, in Prophetic *ḥadīth*, the influence of Aramaic on Qurʾānic Arabic, and the debt of Amharic to Geʾez. Had I listened more to Derek whilst I was at Yale, I might have turned sooner in my academic career to instruments. But I did leave Yale with a copy of his *Astrolabe Checklist*, and it was Derek who indirectly inspired me to embark on the preparation of a catalogue of medieval instruments, a project that in its initial stages relied heavily on his having established the whereabouts of most of these.

A shorter version of this study entitled "14th-Century England or 9th-Century Baghdad? New Insights on the Origins of the Elusive Astronomical Instrument Called the *Navicula de Venetiis*" has recently appeared in *Astronomy and Astrology from the Babylonians to Kepler—Essays Presented to Bernard R. Goldstein on the Occasion of his 65th Birthday*, Peter Barker, Alan C. Bowen, José Chabás, Gad Freudenthal and Y. Tzvi Langermann, eds., 2 pts., *Centaurus* 45 (2003) and 46 (2004), I, pp. 204-226. I am sure my former teacher will not mind me dedicating this version to Derek's memory, since it was Derek in 1960 who, following Robert R. Gunther in 1923, has most contributed to the English literature on the elusive *navicula*, and no less since it was Bernard Goldstein's lectures that I attended at Yale instead of Derek's.

This study, along with **XIIa**, was discussed in my Instrument Seminar in Frankfurt during the Summer Semester of 2002, and I was very grateful for that opportunity to air it in public. I owe a special debt to Sven Ruhberg, a faithful follower of the Seminar over many years, who pointed out to me that the Geneva *navicula* is based on a different construction from the other English *naviculas*. As usual I am indebted to François Charette for his critical reading of the penultimate version of this study, but the remaining problems are nobody's responsibility other than my own.

In seeking the origins of the universal horary dial in a cultural milieu other than the one in which it is first attested, I have tried not to be too polemical or propagandist. I am just trying to address a question that has puzzled a series of scholars for some three-quarters of a century, and although I do not have the answer, I think I know where it may eventually be found.

TABLE OF CONTENTS

1 Introduction, or Why we start with the *navicula* and the universal horary quadrant

> "Since some naviculas are dated from the 13th century it appears certain that Regiomontanus probably only recorded, perhaps modified, the construction, which may therefore have originated with the Greeks, being preserved by the Arabs and revived during the Renaissance." A. W. Fuller, "Universal Rectilinear Dials" (1957), p. 17.
>
> "The navicula ... ... one of the most colourful relics of mediaeval astronomy that have come down to us." F. A. Stebbins, "Portable Sun-Dial" (1961), p. 56.
>
> "Unter Venedigerschiff (Navicula de Venetiis) wird eine kleine Reisesonnenuhr in Form eines mittelalterlichen Schiffes mit hohem Bug und Heck und mit einem Mast bezeichnet, die zur Bestimmung der gleichlangen Stunden in verschiedenen Polhöhen diente. Sie dürfte wohl im 14. Jahrhundert erfunden worden sein." Ernst Zinner, *Astronomische Instrumente* (1967), p. 110.
>
> "A nautically inspired, somewhat whimsical, medieval instrument which derives from the quadrant is the so-called navicula de venetiis." Francis R. Maddison, "Medieval Instruments" (1969), p. 14.
>
> "The navicula is a type of sundial, related to the *Analemma* of Ptolemy, a work translated by William of Moerbeke in the thirteenth century." John D. North, *Richard of Wallingford* (1976), III, p. 113.
>
> " ... I have come to the conclusion that the Little Ship of Venice is a wonderfully constructed instrument which required genius to construct [*leg*. devise] it." J. Kragten, "*Navicula*" (1989), p. 23. [This, even though the author thought the device achieved only an approximate solution.]
>
> " ... this little brass sundial could indicate the time to within about a quarter of an hour, quite adequate for 15th-century needs." Christopher Daniel, "Greenwich *Navicula*" (1992), p. 37.
>
> " ... either 15th century, or an Italian bauble made for the Grand Tourist in the 19th." Arthur Middleton in *BSIS*, no 37 (June, 1993), p. 33, on the 14th-century English *navicula* now in Geneva, after it had fetched £36,000 at auction at Sotheby's of London on 25.02.1993, having been written up in the auction catalogue as "English, possibly 18th century".
>
> "Also on the back (of the *navicula*) is an unequal hour quadrant for converting time in equal hours found by the sundial [*sc*. the universal horary dial on the front of the *navicula*] into unequal or planetary hours." Jim Bennett, "Oxford *Navicula*", on EPACT website.
>
> " ... what in the last resort is the strongest reason for (King's) ascribing the *navicula* to Habash? Only that a trigonometric analysis of the instrument can yield a formula mathematically equivalent to one known to Habash. Such a mathematical equivalence, however, proves very little beyond the fact that the instrument was well designed." John D. North, "Review of King, *Mecca-Centred World-Maps*" (2000), col. 749.
>
> "The reverse of the (*navicula*) carries a second dial, in the form of a *quadrans vetus*, which could be used to provide the unequal hours of the day from sunrise to sunset, while the front of the dial gave the equal hours." Hester Higton, *Portable Sundials* (2001), p. 28.
>
> "The (*navicula*) appears to have been a modification of the Arabian *zaouraq* meaning small ship (Latin, *navicula*)", Internet site offering facsimiles of historical instruments, including gilded *navicula*s (see n. 2:8).
>
> "(The *navicula*) is a favorite because of its charming shape. This in spite of the fact that it is fundamentally flawed as a timekeeping device. But hey, who uses a sundial anymore for accurate time?" Richard A. Paselk, "Instruments" (Internet site) (2001).

The medieval English instrument for timekeeping by the sun known as *navicula de Venetiis*, "the little ship from the Venetians", has had a very chequered career in the modern literature; indeed, one could argue that no single historical instrument was so misunderstood by several

generations of scholars in the 20th century.[1] Yet there are good reasons why this should have been the case, and why only now we can begin to see some light at the end of the tunnel. The most important component of the *navicula*, with its distinctive, and identical, forecastle and sterncastle at each side, is a universal horary dial with which one can find the time of day in equinoctial hours[2] more or less accurately[3] from the solar altitude and the solar declination for any terrestrial latitude. Yet the available medieval texts on the *navicula* imply, and a series of modern scholars have accepted, that this device functions only approximately. Until recently, we knew only of one crudely-made medieval *navicula*, preserved in Oxford, and one carefully-made but apparently incomplete *navicula* (incomplete not because it lacks the "fo'c's'ls" fore and aft), preserved in Florence.[4] However, just in the last 15 years, three other 14th-century examples—which I label Greenwich, Colchester and Geneva—have been rediscovered, so the time is ripe for a new look at the *navicula*.[5]

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[1] I have already hinted at some of the findings of this paper in King, "Astronomical Instruments between East and West", p. 151, and *idem*, *Mecca-Centred World-Maps*, pp. 351-359. A shorter version is King, "*Navicula*". Since then the website "EPACT: Scientific Instruments of Medieval and Renaissance Europe" has appeared at www.mhs.ox.ac.uk/epact, and I have included references to the instruments that are featured there (Summer, 2002). See also n. 1:13 below.

[2] Equinoctial or equatorial hours are 1/24 divisions of the day and night; seasonal day and night hours are 1/12 divisions of day and night, respectively. Thus, for example, seasonal day hours are longer in summer than in winter and equal to equinoctial hours at the equinoxes. In the Middle Ages tables were available for converting from one to the other: see, for example, **II**, *passim*, tables of the lengths of the seasonal hours in equinoctial degrees throughout the year. It should not be thought that timekeeping in seasonal hours was necessarily any less accurate than using equinoctial hours. See also n. 3:6 below.

[3] We are dealing with instruments small enough to be held in the palm of one's hand, on which the divisions on the various scales are rather crudely marked. Nevertheless we shall find that it is possible to distinguish between instruments that either (1) have the theoretical potential to yield exact solutions, or (2) are so constructed that they can yield only an approximate solution. The *modus operandi* of the two types is different. Since the instruments are so small, this does not necessarily mean that properly-executed examples of the two kinds would in practice yield noticeably different results. The remarks refer only to the *universal horary dial* on the *navicula*: the results that one can obtain from the *universal horary quadrant* on the back of the *navicula* are different in essence and noticeably less accurate.

[4] All medieval instruments have been assigned an International Instrument Checklist number (here prefixed by #), continuing a tradition inaugurated by Derek de Solla Price and his colleagues. The only *navicula*s from before 1500 known before 15 years ago were:

#8531—Oxford, Museum of the History of Science, inv. no. 54358 (formerly G73)—see Gunther, *Early Astronomy in Oxford*, II, pp. 40-41, also Zinner, *Astronomische Instrumente*, pp. 111 and 116, and Price, "*Navicula*", p. 401, both based on Gunther; Brusa, "Navicelle", p. 55 and figs. 3-4; and Bennett, "Oxford *Navicula*", on the website EPACT. This piece is usually falsely described as German (although Jim Bennett has now "origin unknown"); it is fact a crude version of the English instruments listed in n. 2:8 below. In particular it lacks the geographical and calendrical information.

#8532—Florence, Museo di Storia della Scienza, inv. no. 3163—see Brusa, "Navicelle", pp. 56 and figs. 7-8; and A. J. Turner, "Florence *Navicula*", on the website EPACT. The provenance of this piece is not immediately evident, since it is different in style from the English *navicula*s, and resembles a dial described in a 1434 German manuscript (see **Fig. 10a**) but the universal horary quadrant has a somewhat absurd fixed cursor for latitude 52° (England? Oxford??). A. J. Turner describes the piece as 15th-century English without noting the latitude on this scale. See further **6c**.

[5] See n. 2:8 below. Readers familiar with the secondary literature will note that these instruments have previously been described as "15th century". One reason for assigning them to the 14th century is that we have two dated English astrolabes and two dated quadrants from the 14th century, and the three "new" *navicula*s look even older than these. These four pieces are:

Before we can understand the main markings of the *navicula* and their origin, we must first appreciate the two sets of secondary markings on the back of the instrument as well as on the backs of most astrolabes. These are a set of circular arcs for finding the time of day approximately in seasonal hours, which I call the "universal horary quadrant" (see below), and a pair of scales for measuring shadows. Now the combination of these markings superposed one on top of the other (and fitted with an optional solar scale) was known in medieval Europe from the 12th century onwards and was called *quadrans vetus* (see **Figs. XI-6.2.1** and **XIIa-2c**). In a parallel study I have published an anonymous Arabic text on this instrument from 9th-century Baghdad and the subsequent fate of the principal component of that instrument in the Islamic world and in Europe, thereby, I trust, dispelling any misconceptions that this device was actually invented in Europe.[6]

Now the universal horary quadrant provides an approximate solution to the problem of determining time from solar altitude. Since one does not need an instrument that has two sets of markings both yielding (different) approximate solutions, one should expect that the universal horary dial on the *navicula* should provide an exact solution. In fact, the universal horary markings on the front of one variety of the *navicula*, if used properly, do provide an accurate means, if more complicated, of measuring the time in *equinoctial* hours.

Even those modern scholars who have claimed that the horary dial on the *navicula* also provides only an approximate solution have argued for an Islamic origin for the underlying idea, if for entirely the wrong reason (see **Figs. 17.1-2**).[7] Already in 1819, Jean-Baptiste

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#291—English astrolabe dated 1326—London, British Museum, inv. no. 1909 6-17 1—see Gunther, *Astrolabes*, II, pp. 465-467 (no. 291); *London BM Catalogue*, pp. 112-113 (no. 325) and pl. LI; also EPACT. #292—English astrolabe signed by Blakeney and dated 1342—London, British Museum, inv. no. 53 11-4 1—see Gunther, *Astrolabes*, II, pp. 468-469 (no. 292); *London BM Catalogue*, pp. 113 (no. 326) and pl. LII; also EPACT.

#5521—English quadrant dated 1398—Dorchester, Dorchester Museum—see the discussion in *London BM Catalogue*, pp. 55-56 (no. 146), and pls. XVII-XVIII; and Ackermann & Cherry, "Three Medieval English Quadrants".

#5522—English quadrant dated 1399—London British Museum, inv. no. 60 5-19 1—see *London BM Catalogue*, pp. 55-56 (no. 146), and pls. XVII-XVIII; G. Turner, "Whitwell's Addition to a 14th-Century Quadrant"; Ackermann & Cherry, *op. cit.*; and EPACT.

Another reason is that our entire dating of early medieval French astrolabes has been shown to be too late: see King, *Ciphers of the Monks*, p. 397, text corresponding to nn. 18-19.

Readers should also bear in mind that I am one of those (the others are the two historians of Islamic and medieval European astronomy, Paul Kunitzsch and Julio Samsó, and the Catalan palaeographer Anscari Mundó) who believe that the so-called "Carolingian astrolabe" (#3042—Paris, Institut du Monde Arabe, inv. no. AI 86-31—see Destombes, "Astrolabe carolingien"; various papers in Stevens *et al.*, eds, *The Oldest Latin Astrolabe*; also King, *Ciphers of the Monks*, p. 440; and now **XIIIa-9**) is a 10th-century production. Others have claimed that it is a modern fake, or at most of 12th-, 13th-, or 14th-century provenance. In King, "Earliest European Astrolabe", published in the volume edited by Stevens *et al.*, I compared the piece with others of 10th-, 11th-, 12th-, 13th- and 14th-century provenance.

[6] **XIIa**, and the summary in King, "Universal Horary Quadrant". On the development of shadow scales in general see **XIIa-B**.

[7] See Fuller, "Universal Dial", pp. 17-18; Archinard, "Geneva *Navicula*", pp. 87-88; also Price, "*Navicula*", pp. 399-400, and Eagleton, "*Navicula*", 6.1.

The main reason advanced for this alleged Islamic origin in the 20th century was off the mark. Robert Gunther

Delambre, who was well versed in Islamic spherical astronomy but who inevitably knew nothing of the *navicula*, suggested that Regiomontanus had taken his *Uhrtäfelchen* from Arabic sources.[8] So, from the outset, the reader should keep in mind that we have already established that two of the three components of the *navicula* have their origin in 9th-century Baghdad. We are here concerned mainly with the universal horary dial.[9] The *navicula* includes the earliest form of universal horary dial that survives, and there can be no doubt that the *navicula* as we know it hails from 14th-century England (see **6**). However, as I shall attempt to show, the device, not necessarily in the form of a ship, is probably much older. Indeed, at the risk of embarking on a kind of "cultural contest",[10] I—inevitably—favour 9th-century Baghdad over 14th-century

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in 1923 (*Early Science in Oxford*, II, p. 40) drew attention to the existence of an unusual astrolabe rete called *zawraqī*, with a "ship-shaped" horizon on the rete, in the treatise on astronomical instruments by the late-13th-century Cairo astronomer Abū ʿAlī al-Marrākushī, and he wondered if this might be related to the *navicula*. Derek Price in 1960 asserted definitively that it indeed was (Price, "*Navicula*", p. 400), though Giuseppe Brusa was not so sure (Brusa, "Navicelle", p. 52, citing the *zawraqī* markings on an Indian astrolabe in Gunther, *Astrolabes*, I, p. 218). In fact it is not related, for the *zawraqī* markings on a rete are simply a horizon for a specific latitude: see Gunther, *Astrolabes*, I, fig. 94 on p. 193, for some more illustrations, together with the special plate which is to be used with these markings, as well as *Khalili Collection Catalogue*, I, pp. 230, 232, and King, "Review", col. 254b, also n. 17:4 below. In spite of my efforts to kill the *zawraqī* / *navicula* myth (in King, "Universal Solutions from Mamluk Egypt and Syria", first published in 1987, repr. in *idem*, *Studies*, C-VII (and in **VIb**), p. 176) this error has been repeated several times in the past decade or so and is now established as truth on the Internet (see the quote at the beginning of this study). See also Charette, *Mamluk Instrumentation*, pp. 80-81, where the associated heliocentric/geocentric issue is properly discussed. In Eagleton, "*Navicula*", 2.3, on the other hand, we see an orange light because the author had had a look at Sédillot:

> "Instead of jumping to conclusions about relationships between an obscure type of astrolabe and an obscure type of sundial we should perhaps concentrate on those things for which we have better evidence."

Some colleagues have actually driven through a red light at speed. The most ridiculous interpretation of the *zawraqī* astrolabe is in Sezgin & Neubauer, *Wissenschaft un Technik im Islam*, II, p. 16, where al-Sijzī's *asṭurlāb zawraqī* becomes a three-dimensional planetarium, with an equally fictional self-rotating terrestrial globe associated with the Caliph al-Maʾmūn at the centre. At least the authors admit:

> "Ob al-Siǧzī selbst ein Planetarium gebaut hat ist nicht bekannt; unser Modell dient dazu, seine Vorstellung über die Bewegung der Erde zu illustrieren."

In fact, however, it is certain that al-Sijzī never even conceived such a device, as al-Bīrūnī's and al-Marrākushī's diagrams of the *zawraqī* astrolabe rete (**Figs. 17.1-2**) bear witness.

Alas, once an error is entrenched in the secondary and tertiary literature, it is naïve to think that any new scholarly studies pointing out the error will save the situation. (In 1979 I wrote "Ibn Yūnus and the Pendulum", demolishing the myth that the celebrated 10th-century Egyptian astronomer (see n. 5:5) had known the principle of the pendulum, and showing how that myth had come into existence. There are now dozens of sites on the Internet claiming that Ibn Yūnus discovered the principle of the pendulum.)

[8] Delambre, *HAMA*, p. 333.

[9] The best discussion in the modern literature is Archinard, "*Navicula*", although the impression is given that the *navicula* was derived from the *Uhrtäfelchen*.

[10] The expression in relation to the history of medieval instrumentation was coined by John North (see his "Review of King, *Mecca-Centred World-Maps*", col. 748).

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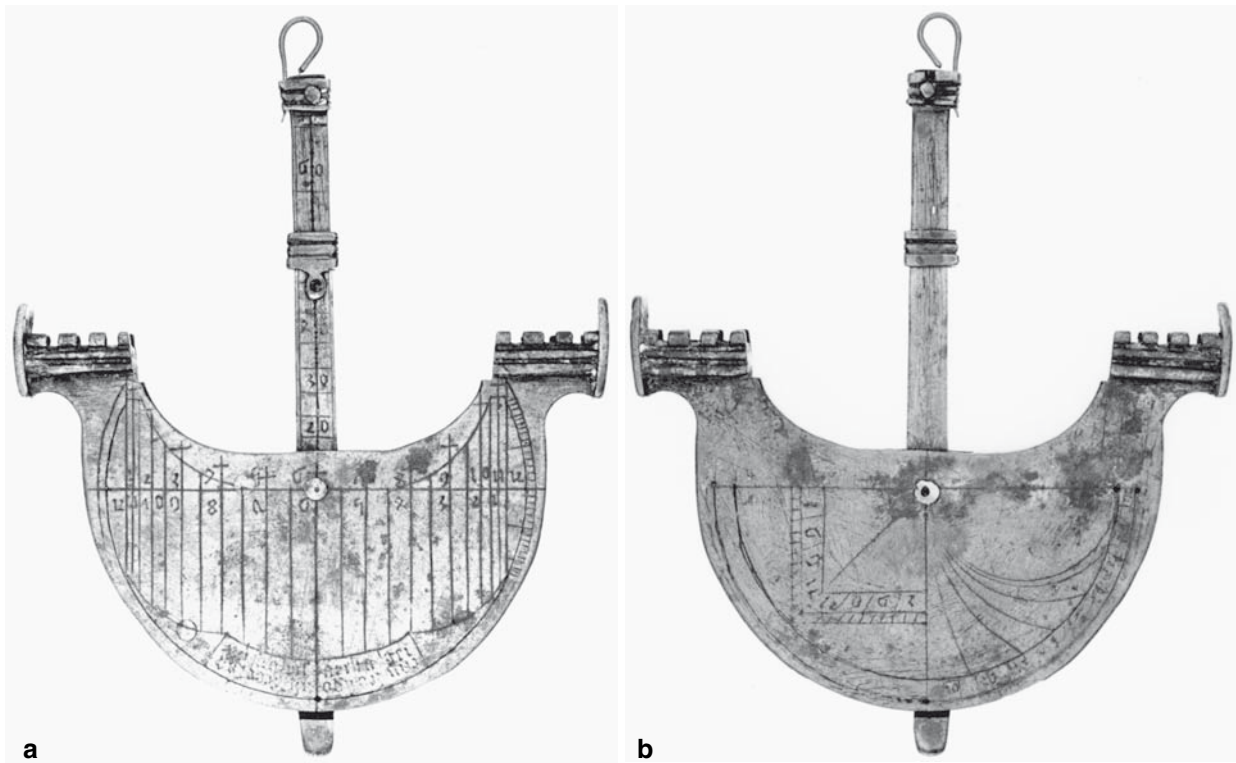
Figs. 2c-d: The front and back of the Florence *navicula* (#8532), corresponding closely to the design proposed in medieval German manuscripts (see **Fig. 10a**) and significantly different in style from the three 14th-century English examples. Nevertheless, the positioning of the fixed declination scale, probably original, on the universal horary quadrant on the back indicates that the piece may be of English provenance. [Courtesy of the Museo di storia della scienza, Florence.]

Figs. 2a-b: The front and back of the Oxford *navicula* (#8531), a crude imitation of better instruments from 14th-century England. [Courtesy of the Museum of the History of Science, Oxford.]

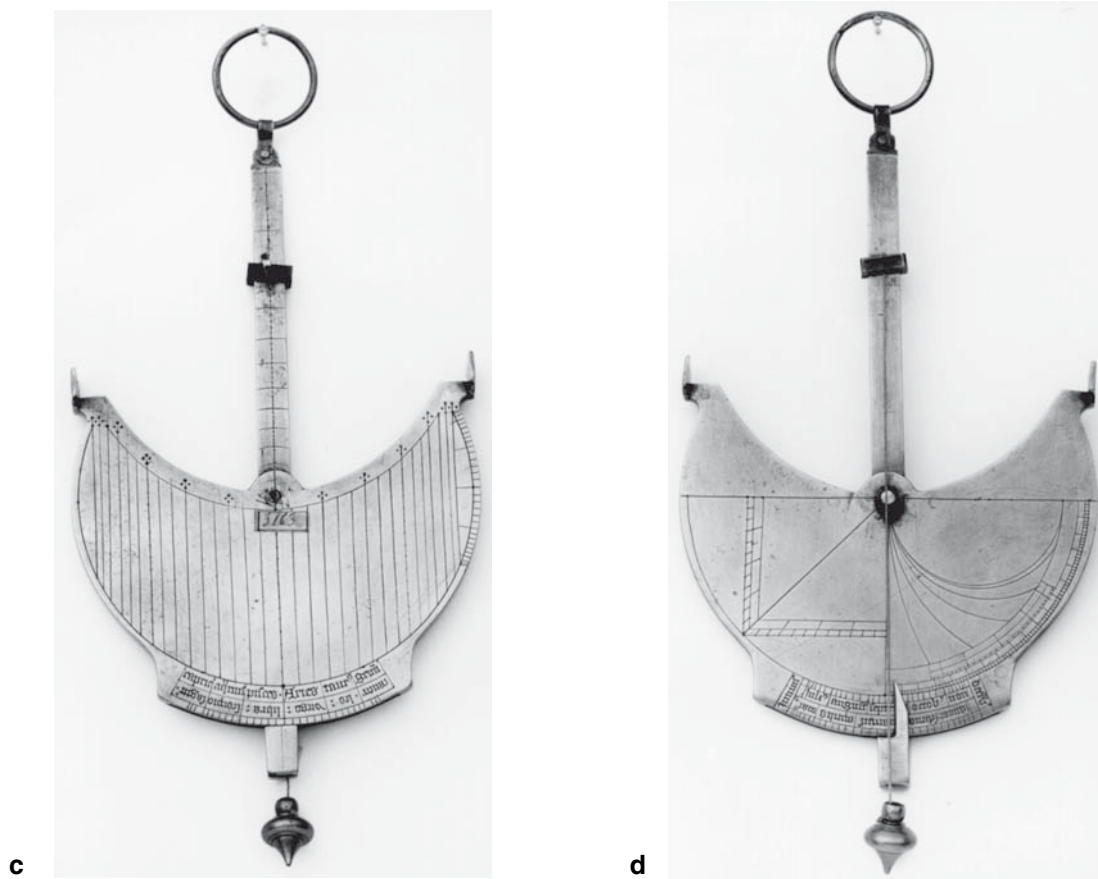
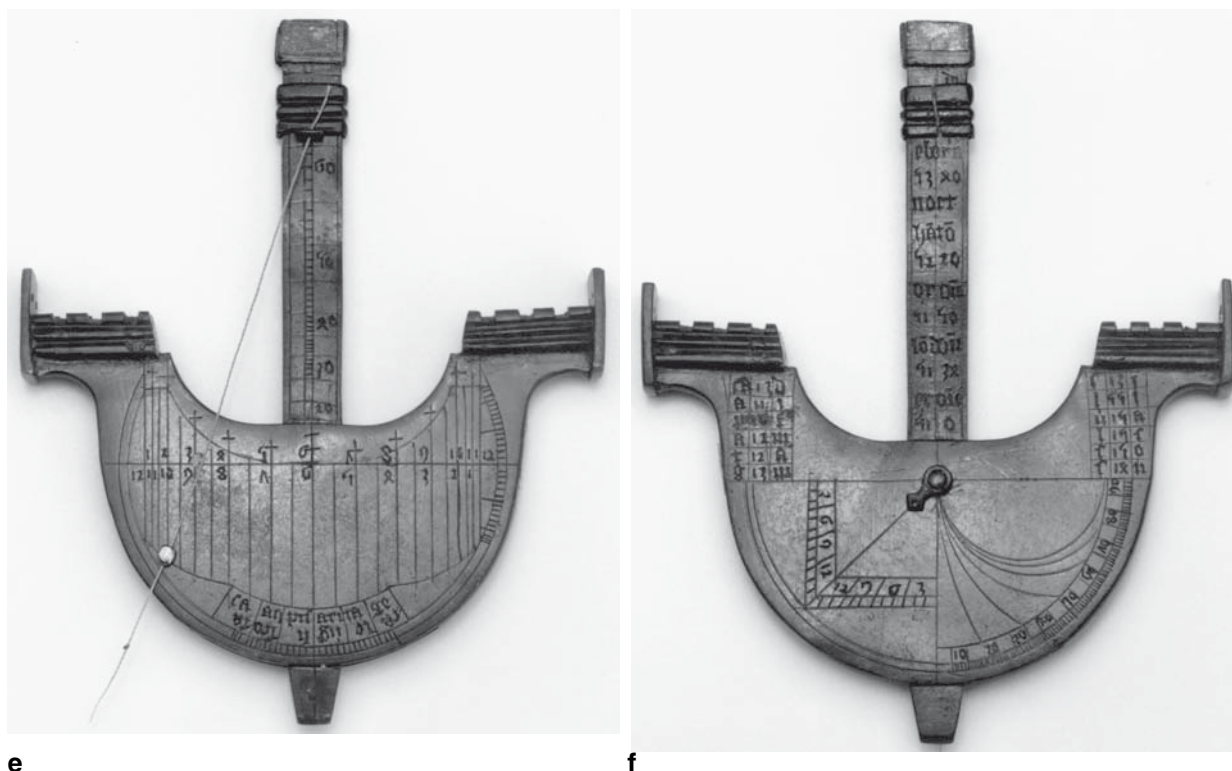



Fig. 2e-f: The front and back of the Greenwich navicula (#8536). [Photos courtesy of the National Maritime Museum, Greenwich.]

England. And I shall suggest that the inventor was probably the extremely innovative astronomer Ḥabash al-Ḥāsib, already well known for his other contributions to mathematical astronomy, mathematical methods and astronomical instrumentation.[11] For, as we shall see, Ḥabash devised a yet more complicated universal instrument for timekeeping by the stars, the components of which are closely related to those of the universal horary dial for timekeeping by the sun (see **12**).

There are two other universal devices for timekeeping that have also had a chequered career in the Middle Ages as well as in the modern literature, namely, the universal horary dial known as the *organum Ptolemaei* and later in a variant form as the "de Rojas projection", but also known to Muslim astronomers in a different manifestation centuries before (see **15** and **16**).

I stress at the outset that **there is no concrete evidence that the universal horary dial was known in 9th-century Baghdad**. But, as we shall see, there are some pointers to the possibility that it might have been, not the least that **all of the main components—the non-uniform**

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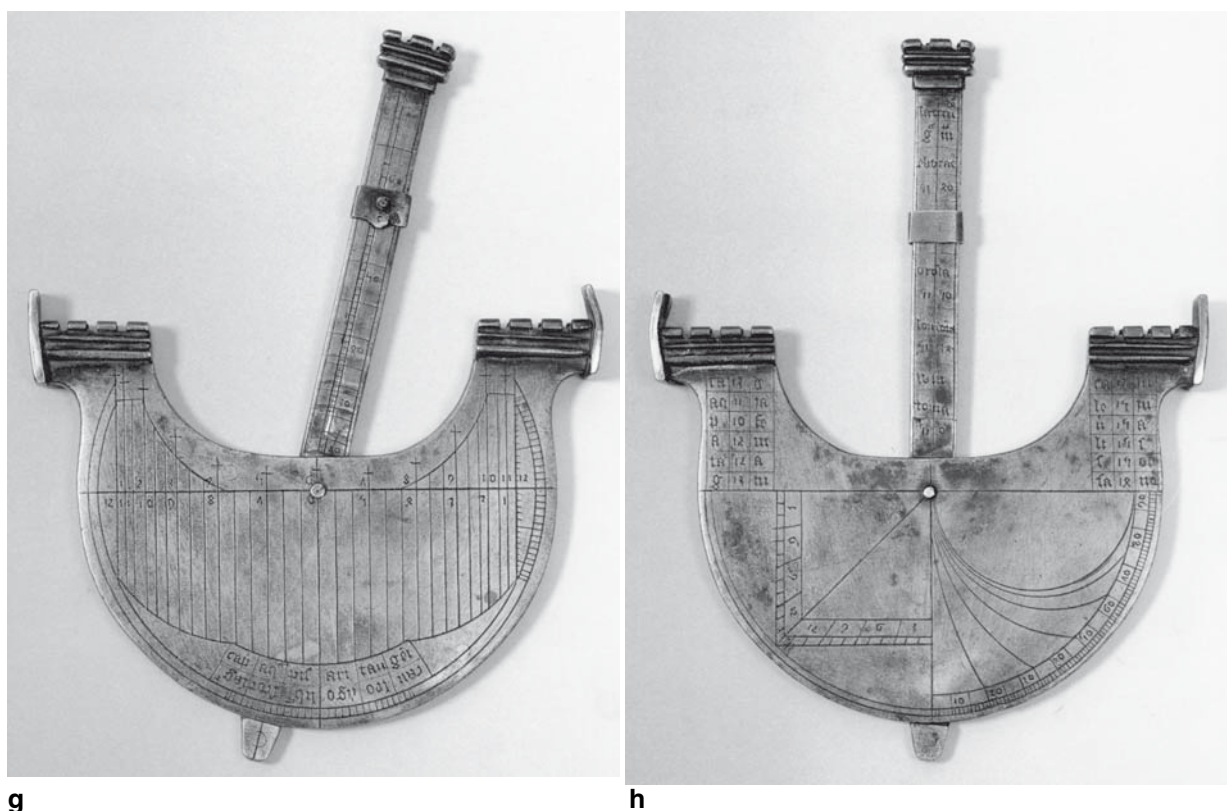
[11] On Ḥabash see the outdated articles in *EI*$_2$ and *DSB*; Sezgin, *GAS*, V, pp. 173-175; and King, *Mecca-Centred World-Maps*, pp. 40-41, 61-64, 345-349, and the references there cited, and also n. 12:1 below. A new account of his achievements by François Charette is to appear in *BEA*.

g h

Figs. 2g-h: The front and back of the Geneva *navicula* (#8537), at first sight virtually indistinguishable from the Greenwich and Colchester instruments. These three pieces define the style of 14th-century English *navicula*s. [Photos courtesy of Sotheby's of London.]

latitude scale, the solar declination scale, and the non-uniformly-spaced horary markings—and the underlying mathematics were known in 9th-century Baghdad. Hence in this study, I make an effort to distinguish between fact and hypothesis. If I allow myself some license it is because I have had the privilege of investigating over 500 Arabic manuscripts relating to astronomical timekeeping from the 9th century onwards: these contain materials undreamed of by medieval European and Renaissance astronomers and guaranteed to surprise a few modern historians of medieval astronomy (see **5** below).[12]

The universal horary dial raises substantial problems for the history of medieval astronomy, in particular for the history of the transmission of scientific innovations from the Islamic world

[12] See **I-II**, and the brief summary in the article "Mīḳāt, ii" [= astronomical timekeeping] in EI_2. On the context of the many tables investigated there see also *idem* & Samsó, "Islamic Astronomical Handbooks and Tables". For the broader context of the history of astronomy in Islam and in medieval Europe see respectively *idem*, "Islamic Astronomy", and McCluskey, *Medieval Astronomy*. On astronomy in medieval England see the various studies of John North. On medieval Islamic and European instruments in particular see, respectively, **X**, and Poulle, "Instruments astronomiques", where the *navicula* is omitted.

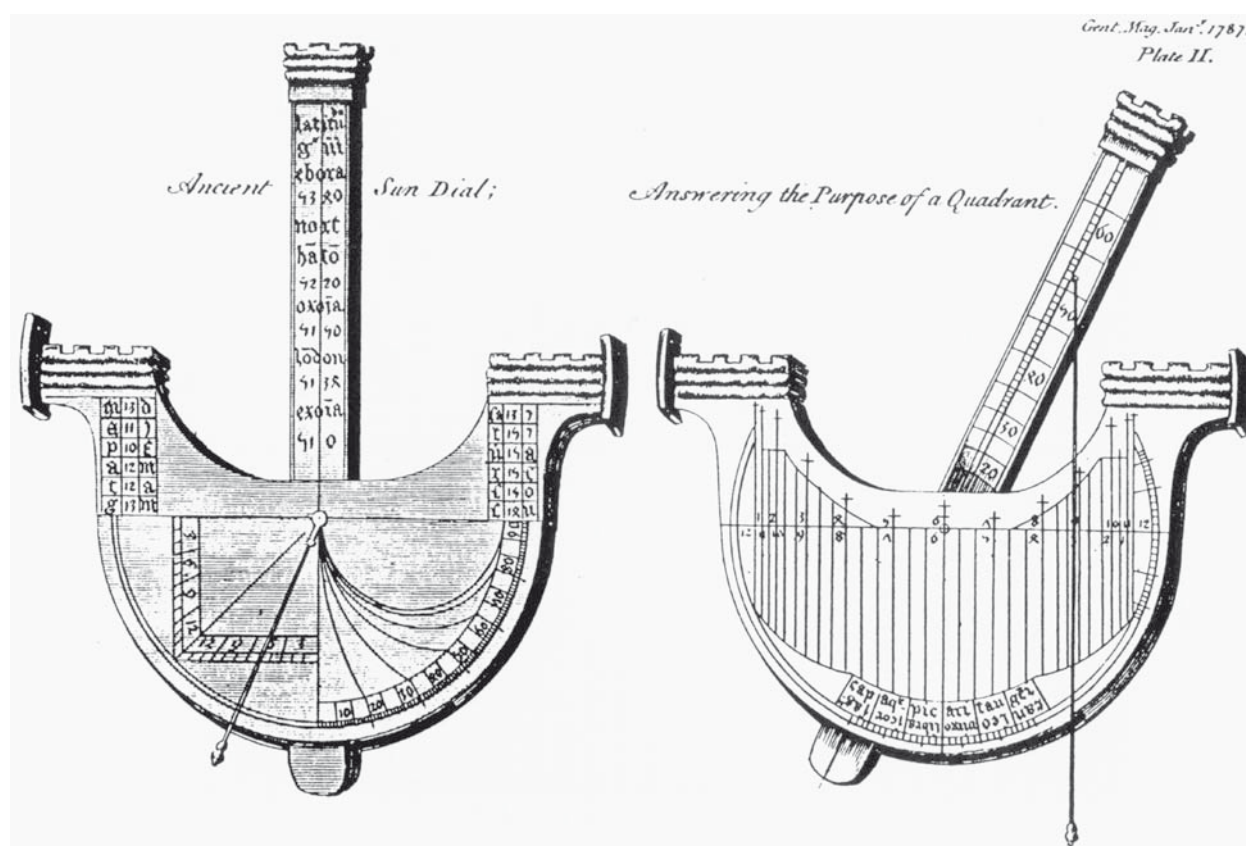



Fig. 2i The Colchester *navicula* (#8538). The text of a letter to the editor accompanying these illustrations published in the *Gentleman's Magazine* of 1787 reads as follows:

> "Colchester, Dec. 7 [1786?]. Mr. Urban, Herewith I send you drawings of both sides of an ancient sundial, answering the purpose of a quadrant, &c. made of brass, the middle, or upright piece of which is moveable to any of the twelve signs. I have been so particular in the delineation as to measure the lines accurately, that any of your readers (if they were so minded) might have one made from the copy as correct as the original. Yours, &c. W.B."

The illustrations have been prepared with great care; nevertheless, note that the subdivisions of the side scale for the tangent of the declination have not been drawn—I suspect that the artist did not realize their significance. [From Delehar, "Illustrations", p. 387.]

to medieval Europe. My study also demonstrates the importance of looking at instruments in the light of available textual materials and *vice versa*.[13] Alas it contributes but little to our understanding of the way in which the universal horary dial was transmitted to Europe, for it was surely there that one variety of the instrument assumed the form of a Venetian ship.

[13] This study arose during the course of the Frankfurt-based project to catalogue all medieval astronomical instruments (both Islamic and European to *ca*. 1550). Funding for this project (1992-96, Islamic, and 1999-2002, European) was generously provided by the Deutsche Forschungsgemeinschaft. On the aims of the project see King, "Medieval Instrument Catalogue". On some of the results see *idem*, "Astronomical Instruments between East and West". For a table of contents of the catalogue see www.uni-frankfurt.de/fb13/ign/instrument-catalogue.html, and now, for the early Islamic instruments, **XVIII**.

In this study I have deliberately restricted my attention to developments before *ca*. 1550 and to the use of the dials rather than their construction. Whilst I shall point to the possibilities for further research, readers will inevitably find that the present study raises as many questions as it solves. I hope these will be addressed by the next generation of scholars.

2 The historiography of the *navicula* in the 20th century

In the 1920s when Robert Gunther first turned his attention to the *navicula*, only one crudely-fashioned piece in Oxford was known (**Figs. 2a-b**). He maintained that this was German, although, in fact, it is 14th- or 15th-century English; he also published a medieval English text in Latin on the construction and use of the instrument.[1] In the 1950s Ernst Zinner identified a medieval German tradition of the same instrument in a different manifestation (see **10**). Since then we know that the universal horary dial circulated in more than one form, one variety having a rotatable rectilinear latitude scale, on the *navicula* developed into the mast. The other had a *brachiolus* and fixed latitude scale, later adapted by Regiomontanus as his well-known *Uhrtäfelchen*.[2] But Zinner's findings have been ignored by all those who have written on the *navicula* since his time. In 1960 Derek Price published a Middle English treatise on the *navicula*, clearly derived from the Latin one published by Gunther.[3] In 1966-67 John North mentioned that he knew of four manuscripts of *navicula* texts in Oxford and one in London.[4] In 1980 Giuseppe Brusa published an overview of *navicula*s and identified, in addition to various several Renaissance examples, another medieval piece in Florence (**Figs. 2c-d**), which might also be of English provenance, although its design follows the German tradition, and is probably 14th century.[5] Since the 1950s a series of studies has been published in which the *navicula* is presented as an approximate device, following the obscure instructions on the *use* in the medieval English texts.[6] In 1989 Jan Kragten analysed the instructions on the *construction* of the universal horary dial on the *navicula* in these texts and showed that the device that

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[1] On the Oxford instrument see n. 1:4. For the text see Gunther, *Early Science in Oxford*, II, pp. 375-379 and 38-39 (also pp. 40-41).

[2] On the Regiomontanus dial see Zinner, *Astronomische Instrumente*, pp. 110-117. On the underlying mathematics see Delambre, *HAMA*, pp. 326-333; Drecker, *Theorie der Sonnenuhren*, pp. 93-96; Fuller, "Universal Rectilinear Dials", pp. 9-15; Stebbins, "Portable Sun-Dial"; Fantoni, *Orologi solari*, pp. 390-415; Archinard, "Cadrans solaires rectilignes", pp. 162-167; and also de Vries *et al*., "Regiomontanus Sundials". Higgins, "Classification of Sundials", pp. 346-347, and also Archinard, *op. cit*., pp. 168-169, treat the *navicula* as an offshoot of the Regiomontanus dial.

[3] Price, "*Navicula*".

[4] North, "Meteoroscope", p. 58, n. 7.

[5] Brusa, "Navicelle". On the Florence instrument see n. 1:4 and also **6c**.

[6] Fuller (1957) started a tradition in the modern literature in which the *navicula* was regarded as providing an approximate solution to the problem of determining $t(h,\delta,\phi)$. Price (1960) saw no reason to fault his findings. Fuller had even derived the correction needed for the position of the cursor on the mast. Archinard (1995) continues the tradition of Fuller; like him she does not consider the medieval texts but anyway they are irrelevant to her discussion of the Geneva instrument (with which there is no error at all when the instrument is used properly). Fantoni, *Orologi solari*, pp. 410-411, comes close to recognizing the real problem of the *navicula*, but fortunately does not embark on a mathematical investigation of the error.

previous scholars had been thinking of was not that represented by the texts and by the Oxford *navicula*. Nevertheless, we were still dealing with an approximate device. The most serious discussion of the origin and historical sequence of the universal horary dial on the *navicula*, the universal horary dial of Regiomontanus, and the latitude-specific horary dial called Capuchin, is by Girolamo Fantoni (1988), written with a clear understanding of the underlying mathematics, but inevitably misled by some earlier modern writings.[7]

Recently three "new" *navicula*s have come to light. They are properly made only up to a point. The scales on all of them are somewhat problematic when examined closely: these should be investigated afresh. The first is now in Greenwich (**Fig. 2e-f**). In another study that appeared in 1992, Jan Kragten showed that this was related to the Oxford piece, that is, it corresponded more or less to the constructions proposed in the extant medieval texts. The second, formerly in Colchester, is known only from an 18th-century illustration (**Fig. 2i**) that was brought to our attention in 1993.[8] A third, at first sight very similar piece surfaced that same year and is now in Geneva (**Fig. 2g-h**). This was investigated in 1995 by Margarida Archinard,[9] without reference to the English manuscripts, and considering the error inherent in the device when compared with the correct procedure using Regiomontanus' *Uhrtäfelchen*. This, as we shall see, happened to most appropriate.

It has not been noted previously that all of these three "new" *navicula*s are 14th-century English, and that at least the Colchester and Geneva pieces possibly hail from the same workshop, if not from the same craftsman. This rather important fact has been overlooked in a flurry of publications on the individual instruments, some by amateurs, some of a non-technical nature and others repeating the approximate nature of the *navicula* (for the wrong reasons), and all overlooking the medieval German tradition.

It has also not been previously noted that the Geneva instrument is based on a construction different from that proposed in the medieval English texts and attested by the Oxford, Greenwich and Colchester instruments.[10] In fact, it is based on what I would imagine is an

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[7] Fantoni, *Orologi solari*, pp. 412-413.

[8] These are:

#8536—Greenwich, National Maritime Museum, inv. no. AST1146—see Kragten, "*Navicula*", Daniel, "Greenwich *Navicula*", Lippencott, "*Navicula*"; and Hester Higton in *Greenwich Sundial Catalogue*, pp. 249-250 (no. 246). The description in Higton, *Portable Sundials*, pp. 26-30, is uninspired, the illustrations miserable, and there is no hint of the *modus operandi*; furthermore, the *navicula* is treated *after* the Regiomontanus dial.

#8537—Geneva, Musée d'Histoire des Sciences, inv. no. 2139—see the description by A. J. Turner in *Sotheby's London 25.02.93 Catalogue*, p. 73 (lot 386) with colour photos on p. 61; G. Turner, *Navicula* (non-technical); and Archinard, "Geneva *Navicula*". Illustrated in King, *Mecca-Centred World-Maps*, p. 354 (Fig. 9.5.2), though there falsely associated with Greenwich!

#8538—present location unknown, formerly Colchester, known only from an illustration in the English *Gentleman's Magazine* of 1787—see Delehar, "Illustrations", pp. 386-388. See also n. App. A:1.

Various Internet sites, some of dubious quality, can be accessed *via* google.com under "navicula" and "venetiis". Acceptable copies of a *navicula* made by Norman Greene can be obtained for just over US$ 100 from http://renaissance-faire.com/shop/timeless-instruments.htm. The illustrations of #8538 can be inspected at Paselk, "Instruments" (www.humboldt.edu/~rap1/EarlySciInstSite/Instruments).

[9] Archinard, "Geneva *Navicula*". See also the next note.

[10] This was first pointed out to me by Sven Ruhberg, but the nature of the Geneva piece is actually already

"original" construction, far simpler than that of the available texts, and we are at liberty to propose for it a different *modus operandi*, without assuming any additional components. I shall refer to this instrument as the "standard" *navicula*, even though we have only one example and no associated texts. As we shall see, if used properly, the "standard" *navicula*, just as it is, can provide an accurate solution for the general case. Also I shall be at liberty to reconstruct its *modus operandi*, since this is not the same as that described in the medieval texts, which relate to the different manifestation of the same instrument, represented by the Oxford, Greenwich and Colchester pieces. I shall refer to that as the "modified" *navicula*, because it was clearly originally derived from the "standard" variety. See further **6b**.

3 On some basic notions in medieval spherical astronomy and instrumentation

a) On latitude-specific and universal solutions

The formulae for solving problems of spherical astronomy serve all latitudes, but the practical solutions to these problems can be either for a specific latitude or for all latitudes. As I have shown elsewhere, Muslim astronomers continued Hellenistic trend in presenting solutions that would serve the whole world, and the instruments and tables that they devised are impressive from a mathematical point of view.[1] Thus, for example, Ptolemy tabulated oblique ascensions for each of the seven climates of Antiquity; several Muslim astronomers compiled tables for each degree of latitude within a reasonable range, say, 0° to 50°. Likewise, the plates of Greek astrolabes were made to serve the seven climates, and Muslim astrolabists made plates for a whole range of latitudes; however, they also devised the universal astrolabe serving any latitude.[2]

I use the term "universal" to describe any astronomical instrument or table that works for essentially all terrestrial latitudes.[3] I use the expression "universal horary dial" to refer to the kind of markings found, *i.a.*, on the front of the *navicula*: they are universal, they serve the determination of the equinoctial hours using the exact formula, and they consist of a set of fixed horary markings to be used in conjunction with an ingenious movable device with thread

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apparent from Archinard, "Geneva *Navicula*". At least the mast scale is in order: the markings correspond to the tangent of the latitude multiplied by the distance from the centre to the 12th hour line. (On the other pieces the mast scale is unhappily based on the radius of the circle bounding the horary markings, so that it contains a factor depending on the obliquity.) The declination scales are not particularly carefully drawn and merit further examination. (At least they are not as different from each other as they are on the other pieces.) Furthermore, only on the Geneva instrument is the chord subtended by the side declination scale, which chord is the 12th hour line, properly marked as a scale for the tangent of the declination.

[1] On universal instruments and tables see further **VIa-b**. Alas the universal horary quadrant was omitted from the earlier studies (first published in the 1980s and reprinted in King, *Studies*, C-VI and VII) on which the new versions are based.

[2] On the concept of universality in relation to the standard astrolabe see King, "Geography of Astrolabes", pp. 6-11 and 14-17. On the universal astrolabe and astrolabic plate and for an overview of the recent literature, mainly by the Barcelona School, see the article "Shakkāziyya" [= universal projections] in EI_2, and for the medieval European tradition see Poulle, "*Saphea*".

[3] In some cases the instruments or tables serve all "reasonable" latitudes, by which I mean the range 25°-50°. One does well not to get involved with latitudes in the tropics or to get too close to the Arctic circle.

and movable bead attached with which one can enter the local latitude and the solar declination. This seems preferable to various other expressions in the modern literature, some with good historical backgrounds, such as "Uhrtäfelchen", "cadran solaire rectiligne", "rectilinear dial", "universal sundial", and "rectilinear altitude sundial".

Likewise, I use the expression "universal horary quadrant" to describe the set of circular arcs for the seasonal hours best known from the backs of astrolabes but also found on the *quadrans vetus* and the back of the *navicula*.[4] Here the markings are universal, the purpose solely to measure the time of day in seasonal hours, and the form usually a quadrant. Other modern expressions, such as "unequal-hour lines", "unequal-hour diagram", and "horary quadrant for planetary hours", have tended to obscure the function and the scope of the markings.

b) On exact and approximate solutions

Medieval astronomers used two different kinds of procedures for determining time from solar and stellar altitudes.[5] The first, by far the most common, involved exact formulae such as we shall discuss in **5** and such as underlies the universal horary dial on the *navicula*. The second involved an approximate formula that works very well in Mediterranean latitudes: it serves to determine the time in seasonal hours from the instantaneous altitude and the meridian altitude.[6] This formula, also trigonometric, underlies the markings on the universal horary quadrant, but, as I have shown in a separate study, also other instruments and various tables.[7] (Another approximate formula, this time arithmetical, was used mainly in folk astronomy and does not concern us here.[8]) In this study, we shall be dealing with the exact procedures possible with the universal horary dial and the approximate procedures achieved by the universal horary quadrant.

c) On some implications for astronomical instrumentation

Exact and approximate markings could be combined side by side or back to front on a compound instrument. It was, for example, a good idea to put a universal horary quadrant on the back of an astrolabe: the quadrant provides a quick approximate solution for any latitude, whereas the front of the instrument provides an exact solution for a set of specific latitudes. Likewise, it was a good idea when a 10th-century astronomer presented two tables for timekeeping: one for the latitude of Baghdad based on the exact formula and another for all latitudes based on the approximate formula.[9] But components based on approximate procedures should not be combined directly. An unhappy combination is found on the *quadrans novus*, on which the approximate markings of a *quadrans vetus* are directly combined with an accurate set of astrolabic horizons for different latitudes.[10] Likewise, one medieval table displaying the

[4] See n. 1:6, and also **9a**.

[5] The reader may compare the tables discussed in **I** and **XI**. For numerous examples of instruments of each kind see now Charette, *Mathematical Instrumentation*.

[6] The solution is approximate because the formula is approximate, not because it involves the seasonal hours.

[7] See **XI**.

[8] See **III-1.3** and **IV-2.4**.

[9] **I-2.3.1** and **2.5.1**, also **XI-3.2**.

[10] **XI-10.3** and **IXa-8**.

time in equatorial degrees for a specific latitude was derived by using the approximate universal formula for timekeeping and then converting the resulting seasonal hours to equatorial degrees. It therefore displays errors to several degrees, whereas most medieval tables based on the exact formula have errors of a few minutes of a degree.[11]

There is a sense in which the universal horary dial and the universal horary quadrant serve the same purpose: both are essentially intended only for timekeeping by the sun;[12] both are universal, but one is exact and the other approximate; one requires some dexterity, especially to arrive at the exact solution, and the other is very easy to use.

On the universal horary quadrant it was acceptable to add an optional solar scale on the rim of the quadrant since this served only to find the meridian altitude from the solar longitude or solar date. But it was inappropriate to add a radial solar scale, necessarily latitude-dependent, to such a device, for this gave a false impression of accuracy and implied that the markings were exact.[13] Thus, Oronce Fine chose to put such a scale for the latitude of Paris on the universal horary quadrant of his ivory *navicula* made in 1524.[14] But the Renaissance astronomers who added such latitude-dependent scales do not seem to have realized that the use of the universal horary quadrant in northern latitudes was inappropriate anyway. The device was invented in latitudes for which it worked rather well, and solar scale was on the rim and movable, enabling it to be used universally. On the universal horary quadrant on the Florence *navicula* (**Figs. 2c-d** and **Sections 6c** and **10**), there is a somewhat inappropriate, fixed declination scale for latitude 52° (England? Oxford?).

I now outline my basic assumptions, to which some readers will surely object. I would first maintain that, for well-informed medieval astronomers:

a) it was important to distinguish between universal solutions and solutions serving a single latitude, it being inappropriate to combine them directly; and
b) it was important to distinguish between exact and approximate procedures, and again preferable not to combine them directly.

Furthermore I would argue that:

c) the person who first devised a universal horary dial capable of yielding an exact solution would have proposed a correct procedure for using it, precisely to produce an exact solution;

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[11] **I-2.3.4** and **XI-3.9**.

[12] A more complex mathematical device is required for timekeeping for any latitude by the stars, since this also involves the sun and various kinds of stellar data must be accessible. Such a device was invented in Baghdad in the 9th century: see now Charette & Schmidl, "Ḥabash's Universal Plate", and **13** below.

The universal horary quadrant can of course be used to find the time of night from the instantaneous and culminating altitudes of any star, but the time is then given in "stellar hours" related to the arc of visibility of the star in question. Only one medieval astronomer is known to me (**I-4.6.1**) who used such "hours".

[13] **XI-11.3-4** and **IXa-14**.

[14] #8533—Milan, Museo Poldi Pezzoli, inv. no. 4277—see Brusa, "Navicelle", p. 55 and figs. 5-6; and Fantoni, *Orologi solari*, pp. 414-415 (front and back).

On the illustrations of the *navicula* in Finus' *De solaribus horologiis et quadrantibus* ... (1560) see n. 10:9.

d) the universal horary quadrant was added to the back of the *navicula* (as to the back of the astrolabe) to provide a quick approximate solution, the universal horary dial (like the front of the astrolabe) providing an accurate solution;

e) the persons who wrote on the universal horary dial later without realizing its full potential or knowing how to use it properly did not devise it;

f) it is unlikely that anyone sat down and devised the "modified" *navicula* from scratch; rather, the "modified" version with its over-complicated construction to produce an approximate solution for the general case was produced *after* the "standard" version, with which an exact solution is possible if the device is used properly.

Finally, I confess that I am at a loss why anyone capable of understanding the use of the "standard" *navicula* would wish to propose a much more complicated procedure to produce the "modified" *navicula*.

4 Notation used in this study

In the sequel I shall first explain the theory underlying the universal horary dial on the *navicula* in terms of modern mathematical notation, albeit using functions that are of prime importance in medieval (Islamic) timekeeping.

Muslim astronomers generally used the sine and cosine function to base 60.[1] This produces occasional complications (if only for a modern not used to sexagesimal arithmetic), especially when multiplying or dividing trigonometric functions. Muslim astronomers generally used base 12 for the cotangent and tangent functions (corresponding to horizontal and vertical shadow lengths). I shall use the standard modern capital notation for medieval trigonometric functions to base R = 60, thus: $\text{Sin}\ \Theta = R \sin \theta$, where Θ is properly an arc and θ the corresponding angle (so the Sine is now a length rather than a ratio), and $\text{Vers}\ \Theta = R - \text{Cos}\ \Theta = R - R \cos \theta$. Thus the trigonometric functions are now lengths rather than ratios, but in the following we shall no longer distinguish between arcs and angles.

The following notation is used freely:[2]

a	azimuth (measured from the east- or west-points)
$\mathcal{B}$	the auxiliary function $\cos \delta \cos \phi$
$\mathcal{C}$	the auxiliary function $\sin \delta \sin \phi$
d	the excess of the half-arc of daylight over 90° (= D - 90°)
D	the half-arc of daylight (the time from sunrise to midday or from midday to sunset)
$\mathcal{E}$	the auxiliary function $\tan \delta \tan \phi$(= sin d)
$\mathcal{G}$	the auxiliary function $\sec \delta \sec \phi$
h	the instantaneous solar or stellar altitude
H	the solar meridian altitude ($= 90° - \phi + \delta$)

[1] For overviews of Islamic trigonometry see Kennedy, "History of Trigonometry"; King, "Islamic Trigonometric Tables" (unpublished); and Debarnot, "Islamic Trigonometry". A new overview taking into consideration the materials in **I-II**, especially that in **I-9**, is a *desideratum*.

[2] The same notation is used in **I** and **II**.

H — as a subscript relates to the horoscopus or ascendant—see λ_H below
$\mathcal{K}$ — the auxiliary function sin h tan ϕ (for azimuth calculations)
$\mathcal{L}$ — the auxiliary function sin δ / cos ϕ (for azimuth calculations)
n — gnomon length or base for shadow functions (usually 12)
R — base for medieval trigonometric functions (usually, but not always, 60—see above)
t — hour-angle, or time before or after midday, measured in degrees (but marked on the scale of the universal horary dial on the *navicula* in equinoctial or equatorial hours)
t* — hour-angle for stars, measured before or after midnight
T — the time of day measured from sunrise before midday or until sunset thereafter (= D - t)
x, y, z — independent variables
α — right ascensions[3]
α' — right ascensions measured from Capricorn 0° ($\alpha' = \alpha + 90°$)
α_ϕ — oblique ascensions at latitude ϕ
δ — solar declination[4]
Δ — stellar declination
ε — obliquity of the ecliptic[5]
ϕ — local latitude
λ — solar longitude
λ_H — longitude of the horoscopus or ascendant, that is, the point of the ecliptic instantaneously rising over the local horizon[6]
θ — independent variable (arc or angle)

5 Aspects of Islamic astronomical timekeeping

a) The problem of reckoning time from solar altitude

The three-dimensional problem of finding t or T—related by T + t = D—from h, δ and ϕ can be reduced to two dimensions using a procedure called the *analemma* and known from Greek mathematical astronomy.[1] But Greek astronomy was not geared to astronomical timekeeping. In fact, Muslim astronomers learned the procedures for deriving a formula for $t(h,\delta,\phi)$ or $T(h,\delta,\phi)$ from Indian sources,[2] which in turn relied on early Greek mathematical procedures.

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[3] See the article "Maṭāliʿ" [= right and oblique ascensions] in EI_2.
[4] See the article "Mayl" [= declination] in EI_2.
[5] See the article "Minṭaḳat al-burūdj" [= ecliptic, also featuring obliquity] by Paul Kunitzsch in EI_2, and also n. 11:3 below.
[6] See the article "Ṭāliʿ" [= horoscopus or ascendant] in EI_2.
[1] On the analemma see Luckey, "Analemma", and the more recent literature cited in King, *Mecca-Centred World-Maps*, p. 15, n. 29, *etc*. (see p. 431 of the index).
[2] See David Pingree's article "Indian Astronomy", in *DSB*, suppl., esp. pp. 571; and also Davidian, "al-Bīrūnī on the Time of Day"; Debarnot, *al-Bīrūnī's* Maqālīd, pp. 36-39; and Plofker, "Spherical Astronomy in Medieval India".

Yet it was the Muslims who, in the 9th, 10th and 11th centuries, developed such projection methods into an art in itself.

Before investigating the possible Islamic origin of the universal horary dial it is necessary for us to appreciate the sophistication of spherical astronomy as practiced by Muslim astronomers. Most medieval Muslim astronomers treated the problem of the determination of t or T in terms of h, δ and φ.[3] For example, Ḥabash proposed the following procedure for deriving time from celestial altitude:

$$T = D - \text{arc Cos} \{ \text{Vers } D - [\text{Sin } h \cdot [\text{Vers } D / \text{Sin } H] \} ,$$

where: $$\text{Vers } D = R + \text{Sin } d ,$$

formulae known already from Indian sources.[4] His successor in spherical astronomy, Ibn Yūnus (*fl*. Cairo *ca*. 990), who was much indebted to Ḥabash, described in words the following procedure (amongst others):[5]

$$T = d + \text{arc Sin} \{ p - \text{Sin } d \},$$

where: $$p = \{ [R \text{ Sin } h / \text{Cos } \phi] \cdot R \} / \text{Cos } \delta ,$$

and: $$\text{Sin } d = \{ [\text{Sin } \delta \text{ Sin } \phi / \text{Cos } \phi] \cdot R \} / \text{Cos } \delta .$$

Neither Ḥabash nor Ibn Yūnus explain the way in which they derived their formulae or could justify them, but these are easily derived from an analemma construction well known to Muslim astronomers from the 9th century onwards.[6] In the early 11th century, al-Bīrūnī was equally at home with procedures involving projections and the other main tool of the astronomers, that is, spherical trigonometry.[7] All of these exact procedures are, of course, mathematically equivalent to the modern formula:

$$\cos t = [\sin h - \sin \delta \sin \phi] / [\cos \delta \cos \phi] = \sin h \sec \delta \sec \phi - \tan \delta \tan \phi .$$

b) Islamic auxiliary functions and tables for timekeeping

Muslim astronomers over the centuries compiled sets of tables of auxiliary functions for facilitating the solution of this and other problems of spherical astronomy. (In the following discussion the trigonometric functions are reduced to base 1.) From the 9th and 10th centuries we have tables of the following functions from the localities noted:[8]

$\sin \delta(\lambda)$ (Baghdad) , $\cos \delta(90°-\lambda)$ (Baghdad, Khwarizm) ,

$\tan \delta(\lambda)$ (Baghdad, Cairo, Iran) ,

$\sin \alpha(\lambda) = \tan \delta(\lambda) / \tan \varepsilon$ (Baghdad, Cairo, Khwarizm) ,

$\mathcal{B}(\lambda,\phi) = \cos \delta(\lambda) \cos \phi$ (Rayy) ,

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[3] On the topics treated in the typical Islamic *zīj* or astronomical handbook with tables, of which we have over 225 from the period 750-1900, see King & Samsó, "Islamic Astronomical Handbooks and Tables".

[4] MS Istanbul Yeni Cami 784,2, fol. 149r. See already Debarnot, "*Zīj* of Ḥabash", p. 48, and also n. 5:13 below. For more detailed treatments of spherical astronomy by Ḥabash see *eadem*, *al-Bīrūnī's* Maqālīd, pp. 45-63; Kennedy & Kunitzsch & Lorch, *Melon Astrolabe*; and Kunitzsch & Lorch, "*Maṭāliʿ al-samt*". On the Indian origin see the references in n. 5:2.

[5] King, *Astronomical Works of Ibn Yūnus*, formulae 14.1.2 on p. 127, and 15.3.2-3 on pp. 147-148. The way in which such formulae are outlined in words is described *ibid*., pp. 66-67. On Ibn Yūnus see my article in *DSB*.

[6] For references see n. 5:1.

[7] See Davidian, "al-Bīrūnī on the Time of Day", and Debarnot, *al-Bīrūnī's* Maqālīd, respectively.

[8] **I-6-7-8**.

$\mathcal{K}(h,\phi) = \sin h \tan \phi$ (Baghdad, Cairo) .

From later centuries we have tables of the following functions for specific latitudes (the digits between curly brackets indicate the number of such tables for different latitudes that have been identified):

$\mathcal{B}(\lambda)$ {20} , $\mathcal{C}(\lambda)$ {17} , $\mathcal{G}(\lambda)$ {4} , $\mathcal{K}(h)$ {8} , $\mathcal{L}(\lambda)$ {4} ,

and of the following for all latitudes (the associated digits indicate the number of such sets known):

$\mathcal{B}(\lambda,\phi)$ {2} , $\mathcal{B}(\Delta,\phi)$ {1} , $\mathcal{C}(\lambda, \phi)$ {0} , $\mathcal{C}(\Delta,\phi)$ {1} ,
$\mathcal{G}(\lambda,\phi)$ {2}, $\mathcal{K}(h,\phi)$ {1} , $\mathcal{L}(\lambda,\phi)$ {1} , $\mathcal{L}(\Delta,\phi)$ {1} .

In particular, Ibn Yūnus appears to have tabulated the very useful function:

$$\mathcal{G}(\lambda) = \sec \delta(\lambda) \sec \phi$$

(actually = $\text{Sec}\ \delta(\lambda)\ \text{Sec}\ \phi / R = R^3 / [\ \text{Cos}\ \delta(\lambda)\ \text{Cos}\ \phi\ ]$) ,

but his table has not survived.[9]

Some astronomers compiled tables for a specific latitude of the functions:[10]

$t(h,\lambda)$ {14} , $T(h,H)$ {7} , $a(h,\lambda)$ {4} ,

and one, Najm al-Dīn al-Miṣrī (Cairo, *ca*. 1325), even went to the trouble of compiling a table of T(h,H,D) for each degree of each of the three arguments, at the cost of computing over 440,000 entries, which served both the sun and stars and worked for all latitudes.[11]

In addition, a dozen or so Muslim astronomers compiled tables of auxiliary functions for solving problems of spherical astronomy.[12] For example, Ḥabash tabulated the functions:

$$F_1(\lambda) = \delta_2(\lambda) = \text{arc tan } \{ \tan \varepsilon \sin \lambda \} \ ;$$
$$F_2(\lambda) = \cos \delta(90°\text{-}\lambda) = \cos \{ \text{arc sin } [\cos \lambda \sin \varepsilon] \} \ ;$$
$$F_3(\lambda) = \cos \lambda / F_2(\lambda) = \cos \lambda / \cos \delta(90°\text{-}\lambda) \ ;$$
$$F_{4a}(\theta) = \tan \theta \sin \varepsilon \ ; \quad \text{and} \quad F_{4b}(\theta) = \tan \theta \ ;$$

and described their use in the conversion of ecliptic and equatorial coordinates. Najm al-Dīn al-Miṣrī wrote a series of instructions on the use of his monumental table of the function:

$$F(x,y,z) = z - \text{arc cos } \{ \text{vers } z - \sin y \bullet [\text{vers } z / \sin x] \}$$

with different arguments to solve all of the standard problems of spherical astronomy. His late contemporary al-Khalīlī (Damascus, *ca*. 1360) tabulated the functions:

$$f_\phi(\theta) = \sin \theta / \cos \phi \ ; \quad g_\phi(\theta) = \sin \theta \tan \phi \ ;$$
$$F(x,y) = \text{arc cos } \{ x / \cos y \} \ ,$$

which are particularly useful for calculating the time of day or night or of solar or stellar azimuths, although al-Khalīlī was even able to explain how they could be used for conversion of ecliptic and equatorial coordinates.

But it was not only strict timekeeping that was served by these tables, because knowledge of the time of day or night is a prerequisite for the practice of mathematical astrology.[13] Another

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9 **I-6.7.1**.
10 **I-2, 5**.
11 On this table, which can also be used as a universal auxiliary table, see **I-2.6.1** and **9.3***, and more especially Charette, "Najm al-Dīn's Monumental Table".
12 **I-9**.
13 Note that in Ḥabash's *Zīj* he treats the problems of determining the time from the solar altitude and

function tabulated by Muslim astronomers, albeit infrequently, was the longitude of the horoscopus, λ_H, as a function of the altitudes of specific fixed stars (Qandahar (?), *ca*. 1000, and Baghdad or Damascus before 1215) or of the solar altitude (Taiz, *ca*. 1300), or at certain times of day (Anatolia, before 14th century);[14] we also find values of useful auxiliary functions such as Vers D and Sin H added to the entries in Ḥabash's star-table in an anonymous recension thereof (Baghdad, 1012).[15]

In medieval European astronomical treatises not directly derived from Islamic sources such as al-Khwārizmī and al-Battānī the problem of reckoning time from solar or stellar altitude by an accurate formula is discussed only rarely. There was some interest in the problem, but far less than in Islamic astronomy.[16] Any historian of medieval European astronomy would get excited if he found *any* table of the kind indicated above in a medieval Latin or vernacular manuscript. In fact, the only one of the above auxiliary tables that appears to have been known in Europe, even in Newminster in 1428, is the table of tan $\delta(\lambda)$ by al-Khwārizmī which ended up in the *Toledan Tables* and which was labelled in Latin *tabula differencie ascensionum universe terre*.[17] European tables of the altitude of the sun at the hours for each zodiacal sign—mainly intended for marking vertical sundials—are well known,[18] but less well known are the extensive tables compiled by medieval Europeans for finding the solar altitude as a function of time,[19] continuing, perhaps unwittingly, the tradition of the more sophisticated (and more useful) Islamic tables for finding the time of day as a function of solar and/or stellar altitude.[20] But the purpose of most of the European tables was quite different from that of the Islamic tables; as Geoffrey Chaucer described them: "*tables ... for the governaunce of a clokke*".[21] Some served astrological purposes, such as the occasional tables of the longitude of the horoscopus as a function of time and solar longitude.[22] Only in the late 15th century, starting with Regiomontanus, did European astronomers begin to compile auxiliary tables, now independently of the Islamic tables, but, inevitably, essentially for the same purposes.[23]

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determining the ascendant from the time one after the other: see Debarnot, "*Zīj* of Ḥabash", p. 48, and n. 5:4 above. For the stars he treats consecutively the determination of the time from stellar altitude and the determination of the ascendant given the degree of midheaven: *ibid*., p. 56.

[14] **I-3.2.1**, **3.2.2**, **3.1.1**, and **II-14.2** (also **IV-5.3**). On the tables for Qandahar see also **IX**.

[15] **I-6.16.3** and also **IX**.

[16] See, for example, North, *Richard of Wallingford*, II, pp. 74-76, and also n. 5:19 below. Why does Richard of Wallingford give a worked example for latitude 45°?? Surely not, as stated by North, because tan 45° is unity.

[17] **I-7.1**. See already North, *op. cit.*, II, pp. 12-14, and *idem*, *Horoscopes and History*, p. 14.

[18] Zinner, *Astronomische Instrumente*, pp. 50-51 and 159; North, *Chaucer's Universe*, pp. 104-130; and **I-4**, and **I-10.1**.

[19] **I-10.1-2**. None of these tables has been published; see Poulle, *Fusoris*, pp. 184-185, for some extracts from a table for Paris.

[20] All such tables are analysed in **I-1-3**.

[21] North, *Chaucer's Universe*, p. 87.

[22] **I-3.0** and **I-10.2**.

[23] For references see **I-10.2**.

6 The origin of the *navicula* in medieval England

a) On astronomical instrumentation in medieval England

A problem we have to confront when dealing with medieval English instruments is that until recently no serious research had been conducted on them (as opposed to texts on instruments[1]) since the time of Gunther,[2] except for Derek Price, who in the 1950s catalogued the instruments in the British Museum.[3] A new catalogue of the astrolabes in another important collection, that of the National Maritime Museum in Greenwich, is in press; this was prepared by specialists in the field.[4] In the past few years, the major collections in Oxford (Museum of the History of Science), London (British Museum), Florence (Museo di Storia della Scienza), and Leiden (Museum Boerhaave) have put descriptions of many instruments on the Internet site "EPACT: Scientific Instruments of Medieval and Renaissance Europe",[5] but there are medieval English instruments lurking elsewhere, in places as close and as far apart as Cambridge, Innsbruck, Liège, Milan, Istanbul, Chicago and Washington. And even though descriptions of some of our sources are now in the public domain, there are still many questions to be addressed. For example, how can we explain the existence of the magnificent Sloane astrolabe, now in the British Museum, for which I would accept Gunther's dating to *ca*. 1300,[6] although it looks as though it belongs at the end of several hundred years of serious concern with astrolabe-making and rete-design. It is true that in recent years close attention has been paid to three 14th-century English horary quadrants for a specific latitude,[7] but nobody has raised the question where the genre came from or looked at any relevant manuscripts.[8] In other words, there is still no "history of astronomical instrumentation in medieval England"[9] into which one can comfortably fit the *navicula*.

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[1] See Gunther, *Science in Oxford*, V (Chaucer on the astrolabe); Price, *The Equatorie of the Planetis* (Chaucer on the equatorium); and North, *Richard of Wallingford* (on that scholar's *rectangulus* and *albion*).

[2] I am thinking specifically of his *Early Science in Oxford*, II, which contains many good descriptions of mainly English instruments. Other medieval English astrolabes were treated in his *Astrolabes*, II, pp. 463-487. Lists of English instruments, many of which were unknown to Gunther, can be found in the table of contents to the Frankfurt catalogue (n. 1:13); most of these have been described in detail, but the catalogue is, of course, not yet available.

[3] See Price, "Instruments in the British Museum", *ad London BM Catalogue.*

[4] See *Greenwich Astrolabe Catalogue*, forthcoming, and also *Greenwich Sundial Catalogue*, already available.

[5] See n. 1:1.

[6] #290 - London, British Museum, inv. no. MLA SL54—see Gunther, *Astrolabes*, II, pp. 463-465 and pls. CXXVI-VII (no. 290); King, *The Ciphers of the Monks*, p. 383 and 389 (on the quatrefoil decoration); and now Ackermann, "Sloane Astrolabe", on the website EPACT. Silke Ackermann also accepts the dating "*ca*. 1300", but now writes "English?" instead of "without a shadow of a doubt English", presumably because the piece contains plates for Rome and Paris.

[7] These are mentioned in n. 1:5. See, most recently, Ackermann & Cherry, "Three Medieval English Quadrants". Price ("Review of *London BM Catalogue*", p. 131) thought these were fakes because of the symbols for the zodiacal signs on the London piece, however, G. Turner ("Whitwell's Addition to a 14th-Century Quadrant") has shown that these were added in the 16th century.

[8] The notion of constructing an axial semicircle on the quadrant to represent solar altitudes at midday and then defining the solar scale by the altitudes on that semicircle for the equinoxes and solstices is extremely ingenious. See further Charette, *Mamluk Instrumentation*, II-3.1.1, and also **XI-11.3**.

[9] I understand that Catherine Eagleton is currently embarking on a doctoral dissertation on this topic at the Whipple Museum for the History of Science at Cambridge University.

b) The textual sources

There is no doubt that the *navicula* as we know it hails from 14th-century England. Robert Gunther in 1923 made reference to a medieval Latin manuscript, in 1622 in the possession of one T. Allen but now lost (?), which contained a treatise entitled *De compositione navis, quadrantis et cylindre* by John Slape, otherwise unknown.[10] MS Oxford Bodleian Bodley 68, which contains the text of a Latin treatise on the *navicula* that was edited by Gunther, was apparently in the possession of one John Enderby of Louth, a chaplain, at the end of the 14th century.[11] In 1976, John North discussed the reference in a medieval Latin manuscript preserved in London that the astronomical instrument called *navis*, probably to be identified with the *navicula*, was invented by a monk named Peter of Muchelney, a Benedictine abbey near Glastonbury in Somerset, a man also otherwise unknown to us.[12]

Note added in 2004: New information on the available medieval English manuscript sources is found in a 2003 paper by Catherine Eagleton, listed in the bibliography as "The Navicula Sundial", and yet more is to be anticipated in the same author's forthcoming doctoral dissertation at Cambridge University.

The author of the surviving Latin text has made his instructions overly complicated, not least by choosing a different base for constructing the scale on the mast, namely, the radius of the outer circumference rather than the distance from the centre to the middle of the scale for the tangent of the declination. The two are related by a function of the obliquity; thus our author has to introduce the obliquity in his construction of the latitude scale. But in addition, he has provided procedures to modify the declination scales for the bead and for the mast, defining functions $\delta_1(\lambda)$ and $\delta_2(\lambda)$, both close to $\delta(\lambda)$. As Jan Kragten alone has shown, with the modified latitude scale and these two modified declination scales, and the *modus operandi* described in the texts, the device provides an approximate solution for the general case. The combination of these modified scales is ingenious, but I make no claim to understand its motivation, especially in the light of the existence of the simpler and more elegant Geneva *navicula*, which, if used properly, can provide an accurate solution for the general case.

I find it hard to imagine anyone who had actually invented the instrument taking this roundabout path. And it is hard to imagine anyone who would propose such a roundabout construction being competent enough to have invented the markings. But, this having been said, it is to the credit of the medieval English author (or his source) that he could adjust the construction of the latitude scale to this new base. The purpose of his instructions, however, was not so much to produce an individual *navicula* but rather to produce three templates for the construction of *navicula*s.[13] The Latin and Middle English texts desperately need to be

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[10] Gunther, *Early Science in Oxford*, II, p. 379; also Zinner, *Instrumente*, pp. 110-111; Price, "*Navicula*", p. 400; and North, *Richard of Wallingford*, III, p. 114. Neither Slape, nor Enderby nor Muchelney are mentioned in the *Dictionary of National Biography*.

[11] Gunther, *Early Science in Oxford*, II, p. 40; also Price, "*Navicula*", p. 400.

[12] North, *ibid*., pp. 113-114. The text reads: *Navem primitus adinvenit quidam monachus monasterii Glastoniensis qui Petrus de Mucheleyo fuit vulgariter cognominatus*.

[13] This raises interesting questions about instrument production in medieval Europe.

edited again using all of the available manuscripts, translated into English, and provided with one commentary explaining the underlying trigonometry, and another attempting to justify it.

I strongly suspect that there was another text describing the "standard" form of the *navicula*. Perhaps this is even extant in the English manuscripts identified by John North.[14] We shall return in **9d-e** to other aspects of the three "proper" *navicula*s (one "standard" and two "modified") in their English context.

c) The Florence *navicula*

My concern now is with the Florence *navicula*.[15] Is it, too, English? It seems so to me, but since it looks just like a trivial modification of an instrument described in a 1434 treatise from Vienna I shall consider it again later in my discussion of German dials (**10**). The instrument is at first sight carefully constructed, but the basic horizontal line through the centre of the markings of the horary dial has not been drawn. Furthermore, there are no subdivisions of the side scale for the tangent of the solar declination. Both of these are in fact unnecessary, since the markings correspond to those described in the English texts.

What might be considered a real lapse of judgement is that there is a fixed solar declination scale on the horary quadrant. The underlying latitude is 52°, which was possibly intended for Oxford, rather than, say, somewhere in Northern Germany.[16] It is, of course, somewhat absurd to provide a solar declination scale on a universal horary quadrant, although this variant of the universal horary quadrant, that is, one provided with a fixed cursor (also mentioned in the 9th-century Baghdad text on the instrument[17]), but we should keep in mind that on this piece there are no special markings for cities on the mast. (It would nevertheless have been a better idea to put a special mark for 52° on the mast.)

Another argument in favour of an English origin is that, as prescribed in the English texts and on the three "new" English *navicula*s the first four hours are divided into three parts, the fifth into two and the sixth is too narrow to be subdivided.[18] Also some of the markings have not been completed, for example, the inscriptions on the latitude scale and the solar declination scale on the universal horary quadrant (there is, of course, already a calendrical declination scale elsewhere on this side of the instrument, and it would have been *un peu de trop* to have

[14] See n. 2:4.

[15] See n. 1:4 and also **10**. Even Fantoni thought it might be German, because of the declination scale for latitude 52°—see his *Orologi solari*, p. 411.

[16] My reason for being inclined towards and English provenance is that I would expect a North German instrument to look a bit different. Unfortunately we have only one medieval example, a quatrefoil astrolabe from Einbeck, near Brunswick, which is undated but can be assigned to the period 1322-42, during which time the maker Ludolfus de Scicte was treasurer of the Cathedral in Einbeck, which position is mentioned in his signature:

#2072—Cracow, Jagiellonian Museum, inv. no. 41/V—see Härtel, "Ludolfus Borchdorp de Brunswik".

But before we dismiss Germany outright, it should be borne in mind that the only other *quadrans vetus* with some sort of markings for a fixed latitude is found on the 16th-century North German instrument illustrated in **Fig. IXa-7a**, which, in addition to the movable cursor, has a mark for the upper limit of the cursor for the 8th climate (but the underlying latitude is 54°!).

[17] See n. 1:6 above.

[18] On the Oxford piece each of the first five hours is divided into two. In the 1434 German manuscript there are no subdivisions.

included a second set of the same inscriptions). It is in order that there be no numbers associated with the horary markings because these are clearly identified by a decorative ❖ (perhaps inspired by the + signs on the hours on all of the English *navicula*s). I know of no other medieval instruments featuring the + or ❖ design identifying the hours on an horary scale, although some astrolabes in the Chaucer tradition use the 23 letters A-Z with a cross of the "potent" variety having serifed extremities ✠ at the top to represent 0 and/or 24.[19]

d) More on the English context

These references and instruments attest to the English milieu in which the *navis/navicula* was introduced, but I may be forgiven for having severe doubts whether an otherwise unknown English monk could have conceived an instrument as sophisticated as the *navicula* in a monastic environment. It is, however, a fact that the *navicula* now in Greenwich was actually found buried on the grounds of Sibton Abbey, a Cistercian establishment near Saxmundham in Suffolk.[20] Whether there were any monks or anyone else in England in the late 13th or 14th century who might, say, have been familiar with, say, the translation of Ptolemy's *Analemma* by William of Moerbecke in the 13th century, I leave for others better qualified than myself to probe.[21] But to devise the universal horary dial on the *navicula*, one needs a lot more trigonometric skill than that necessary for deriving trigonometric solutions from analemma constructions. Certainly John Slape did not invent the cylindrical sundial.[22] It is a mute point what kind of quadrant he might have presented in his treatise: a trigonometric quadrant?[23] A quadrant with horary markings for a specific latitude?[24] A *quadrans vetus*?[25] Certainly also neither John Slape nor Peter of Muchelney invented the universal horary quadrant or the shadow square which are the other main components of the *navicula* (see **9**) and, of course, of the *quadrans vetus* from the 9th century.

e) Why *de Venetiis*?

First, we should consider the possibility that it was not the V*enetii*, the Venetians, who were originally intended. After all, one might expect the Venetians to be called *Venetiani* rather than *Venetii*. The name derives from that of the Veneti, a tribe who inhabited the coastlands of the Northern Adriatic before the Roman occupation. Is it possible that *navicula de Venetiis* in the

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[19] See King, *Ciphers of the Monks*, pp. 305 and 308, and p. 184 on cross-varieties. (The 23 letters are as in the modern English alphabet, but with no J, V for U/V, and no W.)

[20] On this *navicula* from a monastery see **IX-3**, corresponding to King, "Aspekte", p. 141.

[21] It was John North (in "Review", col. 749, see also his *Richard of Wallingford*, III, p. 113) who raised this interesting possibility. But the principle of the universal dial on the *navicula* is not based solely on an analemma. For an horary dial by Bedos de Celle (Paris, 1760) for a fixed latitude which *is* based on an analemma see Rohr, *Sundials*, pl. 37 on p. 96.

[22] The *conical* sundial was first described in 9th-century Baghdad but the accompanying table of shadow lengths serves a *cylindrical* sundial—see **Figs. XI-4.1c-d**.

[23] See King, "al-Khwārizmī", pp. 28-29, Lorch, "Sine Quadrant"; and Charette & Schmidl, "al-Khwārizmī on the Astrolabe", forthcoming .

[24] See King, *op. cit.*, pp. 30-31.

[25] See n. 1:6.

Latin text was already a mistake before it was rendered "lytel shippe of Venyse" in the 14th-century Middle English translation of that Latin text? The expression *navicula de Venetis* (with one i rather than two) would refer to a completely different scene: I have wondered whether there might have been in medieval English folklore—as there was in Roman Britain—some conception of the ships of the second tribe called Veneti, a Celtic tribe of ancient Gaul (not unrelated to the original Veneti, as it happens). These Veneti inhabited an area of Brittany now in the Département of Morbihan and had a fleet in the Gulf of Morbihan. In 57 B.C.E. they rebelled against Roman rule and were decisively defeated the next year by Julius Caesar in a naval battle, in which, according to his own account in *De bello Gallico*, they lost 220 ships.[26] In spite of the details given by Caesar the form of these remains to some extent conjectural; two were rediscovered by a diver on the bed of the Gulf in the 1950s but then lost to archaeology as a result of human folly.[27] But before I stand accused of the same, we should return to safer ground.

There is a possibility that the form of the ship for the instrument bearing the universal horary dial might have been suggested by a misunderstanding or an over-elaboration of an Arabic term for the movable latitude rule as "the mast of a ship" (see further the end of **14**), but here we are again grasping at straws. It seems much more likely that the ship connection first occurred in Europe, most probably in England. We have already noted the use of *navis* without reference to the Venetians. John North has pointed out that the *Venetii* in the expression *navicula de Venetiis* can refer only to the Venetians.[28] But why did the English choose the Venetians? Perhaps the design was inspired by an English Crusader who had passed through Venice or had seen a Venetian ship somewhere in the Mediterranean. The expression "*de Venetiis*" could also mean "as used by the Venetians", but there is no evidence that any universal horary dial was in use there. And even if Ellis Peters' worthy monk Cadfael, who had a good eye, came back to England from his adventures and escapades in Syria by way of Venice, he is too early for our purposes (Ellis put him into the early 12th century). No other personage comes to mind.[29]

There is a vast literature on medieval ship-design that I have not consulted, save for a recent book on Venetian ships. Lillian Ray Martin of Austin, Texas, who is at once an art historian and a marine archaeologist, has collected over 150 representations of ships and boats in medieval and early Renaissance art—paintings, scuptures, frescoes, mosaics, engravings, manuscript illuminations, *etc*.—from museums, churches, libraries and public buildings in Venice and the surrounding region.[30] See **Fig. 6a** for an example.

But not only the Venetians had such ships. A merchant ship with high foc's'ls fore and aft is depicted in stone in the palace at Bourges of Jacques Coeur (1395-1456), the wealthy French

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[26] On the Veneti and their ships see *Oxford Classical Dictionary*, p. 941, and Craig Weatherhill, "The Ships of the Veneti". See also Muckelroy & Haselgrove & Nash, "A Pre-Roman Coin from Canterbury with Ship".

[27] Weatherhill, *op. cit.*, p. 169.

[28] North, "Review", col. 749.

[29] Though see n. 14:17 below.

[30] Martin, *Art and Archaeology of Venetian Ships and Boats*. See also F. Lane, *Venetian Ships of the Renaissance*, and Congdon, "Venetian Ships (c. 1400)". In this new age, one can actually take a trip on such a vessel: see www.crete-web.gr/cruises/captainhook. On Mediterranean ship-types in general see Villain-Gandossi, "Typologie des navires".

Fig. 6a: A Venetian *nave* illustrated in the treatise on seamanship by Zorzi Trombetta of Modon (1444); the central main mast has not been drawn, but would have been essential. [From a British Library manuscript, reproduced in Martin, *The Art and Archaeology of Venetian Ships and Boats*, p. 89.]
Figs. 6b-c: The seals of Dunwich (*ca*. 1200) and Winchester (13th century) feature not only a ship with foc's'ls fore and aft but also the crescent moon and a star (depicted as a wheel in the former). In the latter, the two figures on the foc's'l aft are presumably trumpeters, rather than sky-watchers (!). [From Kiedel & Schnall, eds., *The Hanse Cog of 1380*, pp. 65 and 79.]
Fig. 6d: A copy of a badge from the late 14th century celebrating Thomas à Becket's return to England in 1170 after six years exile in France. Within four weeks, he was murdered in Canterbury Cathedral. He is shown aboard a square-rigged clinker-built cog, standing to the left of the mast and raising his hand in blessing. [Purchased at the giftshop at Canterbury Cathedral in January, 2004; photo courtesy of Dr. Martin Schmidl]

merchant who served as councillor to Charles VII of France.[31] Also, the spectacular ship of the same kind in silver and partly gilt, made in Nuremberg in 1503 and owned by Wilhelm Schlüsselfeld (1483-1549), is now in the Germanisches Nationalmuseum in that city.[32] More to the point, perhaps, is that such ships were known in England, as shown, for example, by the medieval seals of Dunwich and Winchester illustrated in **Figs. 6b-c**, as well as the pilgrim's badge from Canterbury shown in **Fig. 6d**.

In short, the expression *de Venetiis* remains a mystery.

7 The use of the universal horary dial on the "standard" *navicula*

The universal horary dial on the *navicula* has four scales. The *first scale* is on the mast: a cursor with a thread and bead can move in a groove to enter the latitude (**Fig. 7a**). There are *two declination scales*, the lower one for setting the mast according to the solar declination, and the one at the side for setting the bead in position on the thread again according to the solar declination. One feeds in the solar longitude on a non-uniform scale on a kind of fixed cursor in the form of a circular arc of about one-half of a quarter circle, and the declination is shown on an attached uniform scale (**Fig. 7b**). Both declination scales on the *navicula* are identical

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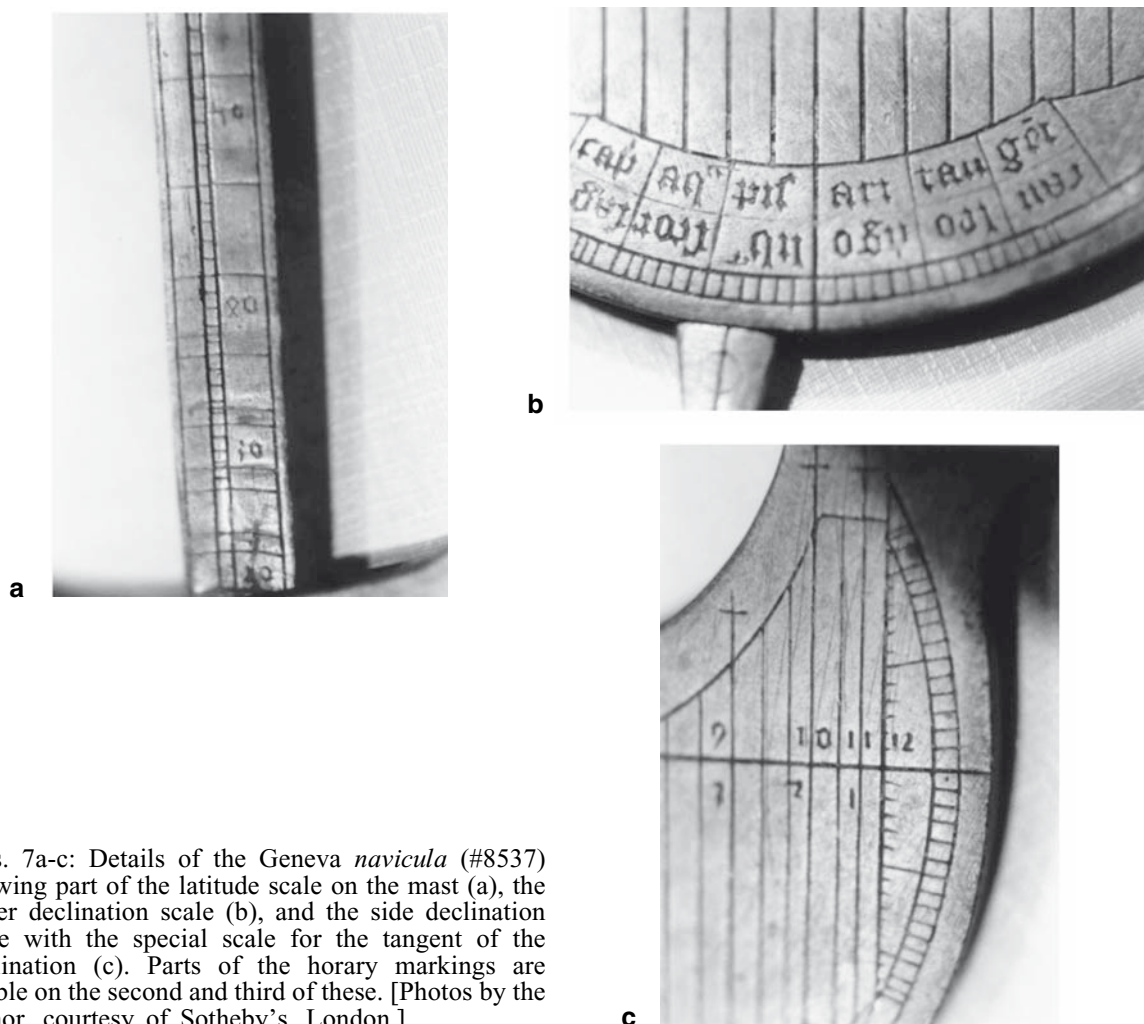
[31] See J. Evans, ed., *The Flowering of the Middle Ages*, pp. 210-211.
[32] See *Nuremberg GNM 1992-93 Exhibition Catalogue*, II, pp. 789-790 (no. 4.4), also featured on the covers of the two volumes, and *Washington 1992 Exhibition Catalogue*, pp. 238-239 (no. 137).

a
b
c
Figs. 7a-c: Details of the Geneva *navicula* (#8537) showing part of the latitude scale on the mast (a), the lower declination scale (b), and the side declination scale with the special scale for the tangent of the declination (c). Parts of the horary markings are visible on the second and third of these. [Photos by the author, courtesy of Sotheby's, London.]

to those on the universal horary quadrant, first described in 9th-century Baghdad and better known from the medieval Latin *quadrantes vetera* and *novi*, although the one at the side of the main markings has an additional scale on the chord joining its ends, which is the scale that actually has to be used (**Fig. 7c**). This second declination scale defines the 12th-hour line (midday), and its distance from the central vertical (6th hour) defines the base for the underlying trigonometry. On the *fourth scale* the hour-lines are drawn and numbered from midnight on the left to midday on the right (see **Figs. 7b** and **7c**).

To use the instrument, we first set the cursor on the mast to the latitude. Then we rotate the mast to the solar declination on the lower scale. Next we set the bead on the thread at the solar declination on the side scale. When the instrument is tilted so that the rays of the sun pass through the hole on the upper sight and fall on the corresponding part of the lower sight, the inclination of the horizontal axis of the instrument measures the solar altitude. The bead then falls on the appropriate marking of the hour-scale. The markings can also be used for

timekeeping by stars whose declination is less than the obliquity of the ecliptic. The "time" measured is time relative to the culmination of the star on the meridian.

Now the way in which these scales are used is critical for the correct application of the instrument. *When the latitude-cursor is set on the mast the bead must first be set so as to rest at the base of the mast.* Then when the mast is turned so that its inclination to the vertical axis of the instrument corresponds to the solar declination, the bead will hang slightly below the horizontal axis. *The latitude-cursor must then be moved slightly upwards on the mast so that the bead falls on the horizontal axis again*. Next when the thread and bead are moved to the side declination scale, *the bead must not be laid on the declination scale itself, but rather on the graduated vertical line segment whose divisions are defined by the scale*.

The following is a free translation of the appropriate part of the Latin and Middle English instructions on the use of the other manifestation of this device:[33]

> "On the mast you can set the instrument to whatever latitude you wish. When you want to find the hour of day first check that the 12 signs on your calendar scale are correctly set forth. Then look at the distance in degrees and signs of the sun from the equinox(es) and solstice(s), and put the mast there. Then hold the thread at the same degree which is on the circular line on which this degree does have or should have* its contact, leading** the pin in the cursor of the mast till the bead is on top of the line of the 12th hour.
>
> * *habet vel haberet / hath or shulde haue* ** *circumducendo / there.aboutledinge*

These instructions do not call for the fine tuning I have proposed because the horary dial has been constructed according to a different procedure.

We may presume that the maker of the Geneva *navicula* was fully aware of the existence of two types of universal horary dial, for he may well have made the Colchester *navicula*, which represents the other tradition. But we may wonder whether there was a second textual tradition in medieval England, documenting the kind of *navicula* represented by the Geneva piece and perhaps proposing the usage I have suggested. Or perhaps no-one knew that such an instrument as the Geneva piece could yield an accurate solution, if used properly. As already noted (**6b**), there are texts available that have yet to be consulted.

In any case, it is hardly surprising that the use of the universal horary dial on the *navicula* has been misunderstood by modern investigators, with the result that without exception they have regarded this function of the instrument as approximate. The errors introduced by not adjusting the latitude cursor and by using the wrong part of the declination scale are, of course, minuscule on an instrument which one can hold in the palm of one's hand, but my point here is that no-one would go to the trouble of designing a brilliant computing device with which an exact solution can be achieved and then himself advocate an approximate procedure for using it. That thereafter others might not have understood the instrument and might themselves

[33] Compare Gunther, *Early Science in Oxford*, II, pp. 378-379, with Price, "*Navicula*", pp. 406-407, and the commentary in Kragten, "*Navicula*". It is a pity that neither version of the medieval text is available in plain English, and that the commentary is not generally accessible.

have proposed a simplified procedure for deriving an approximate solution with it, is another matter. And that someone would propose a device using three sets of modified scales that could yield only an approximate solution for the general case I find completely bewildering.

8 On the mathematics underlying the universal horary dial on the "standard" *navicula*

The formula underlying the operation of the dial can be derived from an *analemma* construction,[1] yet the means of application of this formula does not result only from an *analemma* or any other kind of projection.[2] For it involves a mathematical device for generating mechanically two auxiliary functions of medieval (Islamic) timekeeping, namely, $\mathcal{E}$ = tan ϕ tan δ and $\mathcal{G}$ = sec ϕ sec δ. Once this has been done, one can solve with a minimum of effort what has been reduced to a very simple relation between t and h, namely:

$$\cos t(h,\delta,\phi) = \sin h \cdot \mathcal{G} - \mathcal{E} .$$

With the universal horary dial on the *navicula* and the correct procedure for its use, the determination of $t(h,\delta,\phi)$ is thus achieved. It remains to show how this fits within the framework of early medieval Islamic astronomy. It is not difficult to justify trigonometrically the accurate procedure of the universal horary dial on the *navicula*, for it is, in fact, essentially identical with that outlined by Regiomontanus for his horary dial.[3] But in order to understand the instrument better, it is necessary to consider the steps in which the inventor might have designed it.

We turn to the ingenious trigonometric procedure used by the inventor of the universal horary dial on the *navicula*, bearing in mind that we are interested to generate the two functions $\mathcal{E}$ = tan ϕ tan δ and $\mathcal{G}$ = sec ϕ sec δ. He has exploited a lemma (see **Fig. 8a**):

> Given a triangle OAB right-angled at O, a point C on the perpendicular to OA at A such that AC < OB, and a triangle OCD right-angled at O constructed on OC, in such a way that BD be parallel to OA, then triangle OCD will be similar to triangle OAB.

This is not attested elsewhere in Ancient or medieval mathematics, but the proof is straightforward.[4] Now in a right-angled triangle OAB with horizontal base OA = 1, O = 90°, and A = ϕ, we have OB = tan ϕ and AB = sec ϕ (see **Fig. 8b**). If we then rotate OA by an angle of δ and extend it to OC so that AC is vertical, then AC (on the vertical declination scale) measures tan δ, and OC = sec δ; furthermore, with the triangle OCD similar to OAB we have BD = tan ϕ tan δ = $\mathcal{E}$ and DC = sec ϕ sec δ = $\mathcal{G}$. In this way we have generated the auxiliary quantities $\mathcal{E}$ and $\mathcal{G}$. The procedure is elegant as well as simple and efficacious. The author of the Latin text from 14th-century England complicated matters substantially when he used a base

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[1] See n. 5:1 above.
[2] *Contra* North, "Review", col. 749.
[3] See n. 2:2.
[4] Dr. Jan Hogendijk proposed the following simple proof. Since ∠BOA = ∠ DOC, we have ∠ COA = ∠ DOB (1). Also ∠ A = ∠ B = 90° (2). By (1) and (2) Δs COA and DOB are similar, so OA:OC = OB:OD, hence OA:OB = OC:OD (3), also ∠ BOA = ∠ DOC (4), and by (3) and (4) Δs BOA and DOC are similar. Q.e.d.
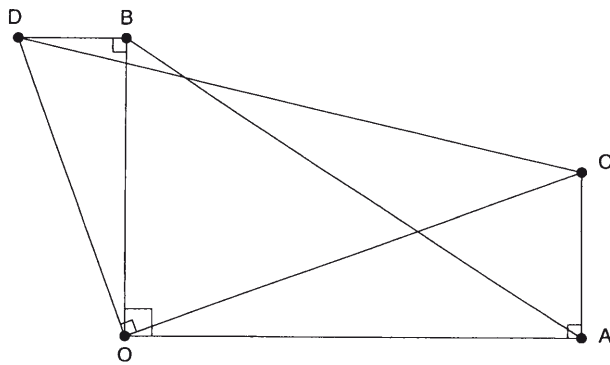
Fig. 8a
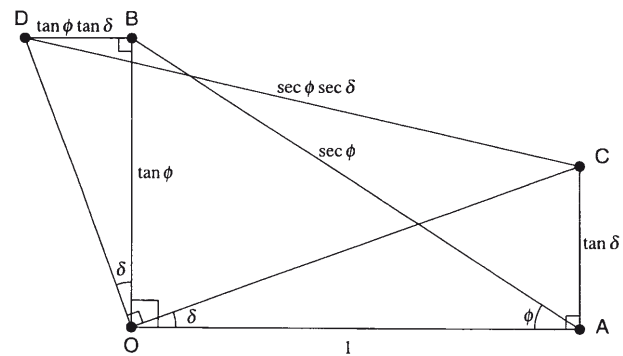
Fig. 8b
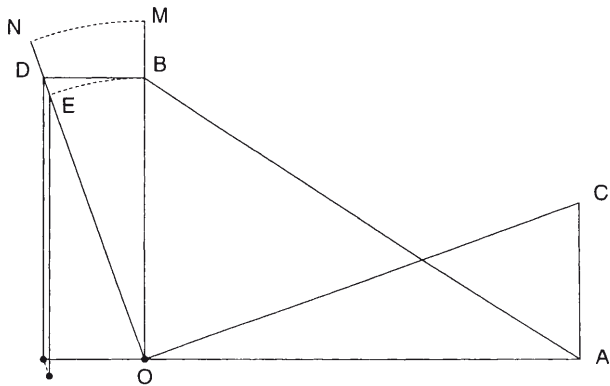
Fig. 8c
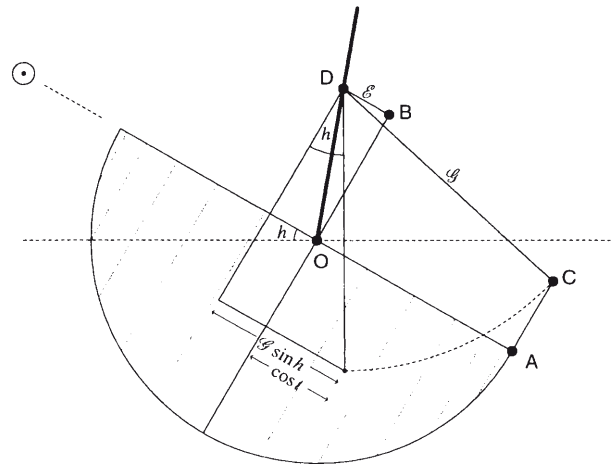
Fig. 8d

other than OA, namely, OC, for the construction of the latitude scale, and then generated two different scales for the declination to produce a different, approximate device.

Now on the universal horary dial on the *navicula*, we have set the cursor on the latitude scale to ϕ in position B (see **Fig. 8c**), with the bead of the vertical thread set at O, and when we rotate the mast by δ (here > 0) to ON the cursor moves from B to E and the bead hangs below the horizontal OA. In order to bring the cursor to D we simply have to move it on the latitude scale so that the bead is again precisely on the horizontal OA. We now move the cursor to the point C on the vertical scale AC measuring tan δ. Then the cursor is at distance BD = $\mathfrak{E}$ from the "vertical" on the *navicula* (that is, the central position of the mast) and the bead at distance DC = $\mathcal{G}$ from the appropriate point C on the vertical tan $\delta(\lambda)$ scale. We now tilt the *navicula* till OA is aligned with the sun (see **Fig. 8d**), and the thread with the bead indicating $\mathcal{G}$ will fall at an angle h to the "vertical" axis of the *navicula*. The bead will then be at

$\mathcal{G}$ • sin h from this "vertical". The algebraic difference between this and $\mathcal{E}$ equals cos t, so the bead will indicate the appropriate time of day on the horary markings.

Now what is the relationship of all this to the procedure of, say, Ḥabash (**5a**)? It suffices at this stage to point out that his ratio Vers D / Sin H is our auxiliary function $\mathcal{G}$, and his Sin d is our $\mathcal{E}$ (**5b**). Also the secant function was more widely known in Islamic astronomy than has been realized hitherto,[5] and the (co)secant function is tabulated in the Berlin manuscript of Ḥabash's *magnum opus*.[6]

9 The other markings on the *navicula*

a) The universal horary quadrant

On the right-hand side of the back of the *navicula*s we find a standard universal horary quadrant with arcs of circles for each of the seasonal hours from 0 (sunrise/sunset) to 6 (midday) and an altitude scale running from 0° at the bottom to 90° at the side. These are precisely the markings on the "*quadrans vetus*" from 9th-century Baghdad,[1] also found on various Islamic astrolabes from the 10th-century[2] and many—but by no means all—later Islamic and European astrolabes. With only the unmarked alidade these markings serve to find the time of day from the instantaneous solar altitude and the solar meridian altitude, for any time of the year and any terrestrial latitude. Now the underlying formula is approximate, but the errors are small for latitudes in the Mediterranean region, and more substantial in Northern Europe. Indeed, for England the error can reach as much as 20 minutes.

If one puts a universal horary quadrant on the back of an astrolabe it is in a sense to double the potential universal application of the instrument. The plates for a series of latitudes—originally for each of the seven climates of Antiquity—provide accurate measures of the time of day in equinoctial or seasonal hours "universally",[3] and the horary quadrant provides a very convenient approximate measure of the time of day in seasonal hours universally. Likewise the universal horary quadrant was put on the back of the *navicula* to provide a second, quick alternative to measuring the time of day in any latitude, this time in *seasonal* hours. If I seem to be repeating myself, it is because I wish to stress this point.

b) The shadow square

On the left-hand side of the back of the *navicula* we find a shadow square with separate scales for horizontal and vertical shadows to base 12 (respectively for h $\gtrless$ 45°). This is one of a series of shadow scales first introduced in 9th-century Baghdad.[4] Greek astrolabes, and with them the

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[5] **I-6.7-9**, also **8.4** and **9.2**.

[6] Kennedy, "*Zīj* Survey", p. 151b. The cosecant function was known to the earliest Muslim astronomers (already in the 8th century) from Indian astronomy: see **XI-2.1**.

[1] See n. 1:6.

[2] See, for example, **Fig. XIIa-10a**.

[3] See n. 3:2 above.

[4] On shadow scales see n. 1:6.

earliest Islamic astrolabes, bore no more than a single altitude scale and an alidade on the back.[5] The shadow square was widely used on Islamic and European astrolabes and other instruments.

c) On the combination of universal horary markings and shadow square

Since the Baghdad treatise described a quadrant with *both universal horary markings and a shadow square*, superposed one on top of the other, these two components went hand in hand in later astronomical instrumentation. This is why we find them both—together—on the *quadrantes vetus* and *novus* and—separate—on the *navicula*.

d) The calendrical data

On the three English *navicula*s from the same workshop and in the English treatise on the *navicula* in Latin (the Middle English version is missing this part) we find a list of dates in the solar year when the sun enters a given zodiacal sign (see **Fig. 9a**).[6] These data can be summarised as follows:

Month	12	1	2	3	4	5	6	7	8	9	10	11
Day	13	11	10	12	12	13	13	15	15	15	15	14
Signs	♑	♒	♓	♈	♉	♊	♋	♌	♍	♎	♏	♐

These dates correspond precisely to the days when the sun at midday has longitude 0;n° (0 < n < 59) in the *Kalendarium* of Nicholas of Lynn, compiled in Oxford in 1386,[7] which may or may not be the source. This work was known and used by Geoffrey Chaucer (d. 1400).[8]

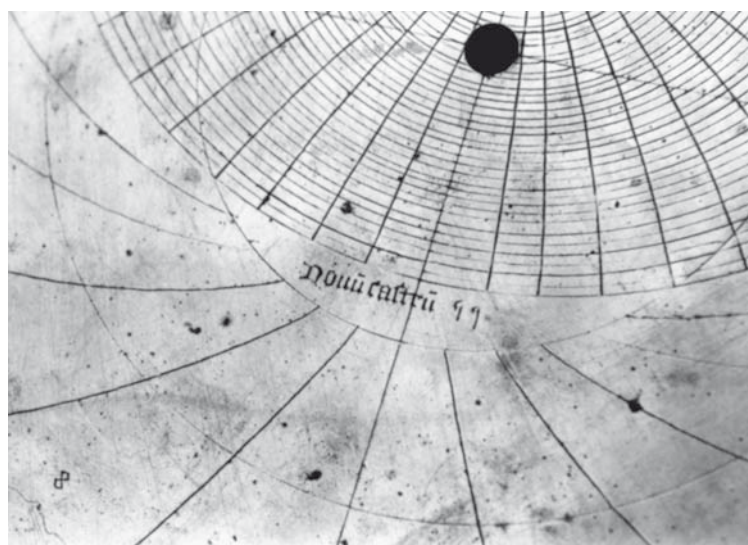
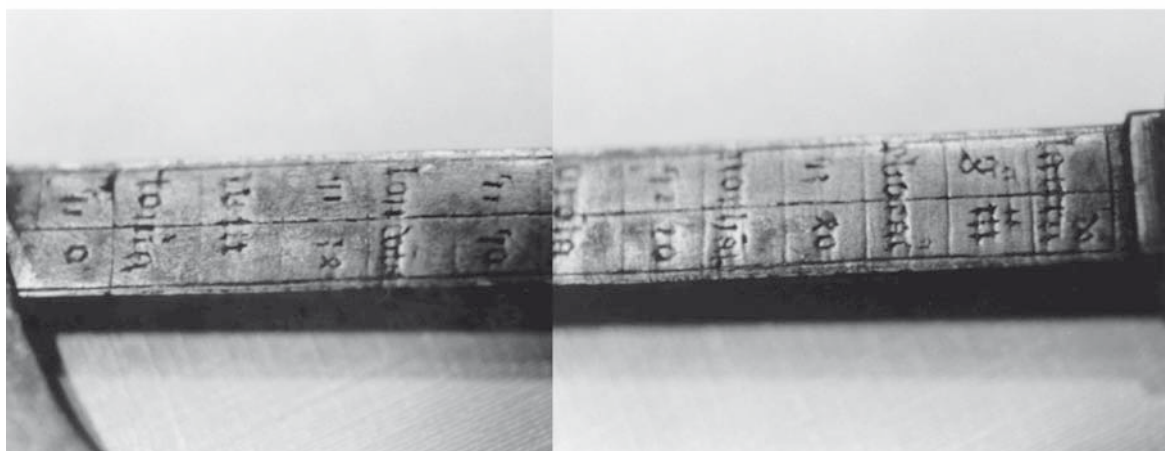
e) The geographical data

Finally, the latitudes of various cities in England are engraved on the backs of the masts of the same three *navicula*s (see **Fig. 9b**). Similar data from the same common source are also

[5] No shadow scales are known from Greek astrolabes or Greek texts on the astrolabe. The absurd shadow squares on the 1062 Byzantine astrolabe:
#2—Brescia, Museo dell'Età Cristiana, inv. no. 36—see Gunther, *Astrolabes*, I, pp. 104-108 (no. 2), after a 1926 study by O. M. Dalton
are a later addition.

[6] Such scales first appear on Islamic instruments in the 10th century but are rarely found thereafter. We may cite:
#1130—undated astrolabe by Nasṭūlus (Baghdad, *ca*. 925)—Cairo, Museum of Islamic Art, inv. no. 15351—unpublished; see King, "Geography of Astrolabes", pp. 29-31.
#107—astrolabic plate with inscriptions in Arabic and Coptic by Ḥasan ibn ʿAlī, dated 681 H [= 1282/83] (Cairo)—Oxford, Museum of the History of Science, inv. no. LE 2019 (new 49861)—see Gunter, *Astrolabes*, I, pp. 239-240 (no. 107); and Mayer, *Islamic Astrolabists*, p. 46.
#4036—astrolabe with inscriptions in Arabic and Coptic by Ḥasan ibn ʿUmar al-Naqqāsh, dated Cairo, also 681 H [= 1282/83]—Istanbul, Türk ve İslâm Eseleri Müzesi, inv. no. 2970—unpublished; see King, *Mecca-Centred World-Maps*, pp. 76-78.

[7] Eisner, ed., *Kalendarium of Nicholas of Lynn*, pp. 64-65, *etc*. Similar lists can be extracted from other medieval almanacs or reconstructed from the calendar scales on medieval instruments. The values in the *Calendar of Cordova* (*ca*. 950) have been shown in Viladrich, "*Mumtaḥan* Influence in the *Calendar of Cordova*", to be derived from tables used in 9th-century Baghdad. On Zacut's table which gives times of entry into the signs to seconds see Chabás & Goldstein, *Zacut*, pp. 45-47, 56 and 109-110.

[8] Eisner, ed., *Kalendarium of Nicholas of Lynn*, p. 2 (intro.), and North, *Chaucer's Universe*, p. 87, *etc*.

Figs. 9a-b: Parts of the calendrical data and the geographical data on the Geneva *navicula* (#8537). [Photos by the author, courtesy of Sotheby's.]
Fig. 9c: The geographical information on three of the plates of this medieval English astrolabe (#4546) is from the same source as that on the three medieval English *navicula*s. [Photos by the author, courtesy of the Tiroler Landesmuseum Ferdinandeum, Innsbruck.]

used for the plates of two 14th-century English astrolabes now preserved in Innsbruck and London (see **Fig. 9c**).[9/10] The latitudes may also be compared with those given in a 15th-century English geographical table associated with William Worcester (b. 1415, WW below), which

[9] #4546—Innsbruck, Tiroler Landesmuseum Ferdinandeum, inv. no. 2957—see King, "Astronomical Instrumentation between East and West", pp. 168 and 189, and *idem*, *Mecca-Centred World-Maps*, p. 352, n. 94.
[10] #298—London, British Museum, inv. no. 1914 2-19 1—see Gunther, *Astrolabes*, II, p. 474 (no. 298), and *London BM Catalogue*, p. 113 (no. 327).

includes some remarkably accurate local coordinates from what John North has hypothesized as a 12th-century source.[11] Details follow:

Location	Greenwich	Geneva	Colchester	Innsbruck	London	WW (no.)	modern
York	53;40°	53;40°	53;40°	53;40°	54°	53;40° (202)	53°58′
Northampton	52;50	52;20	52;20	52;50	-	52;50 (193)	52°14′
Oxford	51;50	51;50	51;50	-	52	51;50 (174-6)	51°46′
London	51;34	51;34	51;34	51;34	-	51;34 (164)	51°30′
Winchester	51; 0	51; 0	-	-	-	50;15 (151)	51°04′
						50;25 (152)	
Exeter	-	-	51; 0	-	-	51; 0 (155)	50°43′
Nottingham	-	-	-	-	53	53; 0 (195)	52°58′
Berwick	-	-	-	-	56	56;50 (207)	55°46′
						57; 0 (208)	
Newcastle	-	-	-	55	55	55; 0 (205)	54°59′
Dover	-	-	-	-	51	50;40 (153)	51°08′

The frequency of occurence of such data on a group of instruments can be taken as a guide to their provenance.[12] Here the most likely locations for the *navicula* workshop are London, York and Northampton, and perhaps also Oxford although this is omitted from the Innsbruck astrolabe. I suspect that the choice of cities featured on any new instrument depended entirely on the whim of the maker on the day he turned his attention to this feature on the instrument.[13]

These data should be compared with those in other unpublished medieval English geographical tables.[14] If their source could be identified, this might constitute an important contribution to the history of the universal horary dial in its medieval English manifestation. If North's hypothesis about a 12th-century origin of these data is correct, a possible candidate for instigating such accurate measurements would be ʿAbd al-Masīḥ, active in Winchester in the 2nd quarter of the 12th century,[15] although the latitudes used in our sources for that city in

[11] The list occurs in MS Oxford Bodleian Laud Misc. 674, fols. 73r-74r, copied in 1438. See further North, *Horoscopes and History*, pp. 186-195. On William Worcester see *idem*, *Richard of Wallingford*, III, p. 242.

[12] King, "Geography of Astrolabes", pp. 5-6, now in **XVI-1**.

[13] The reader will observe that my interpretation of these data is quite different from that in Higton, *Portable Sundials*, p. 30, where it is suggested that the choice of cities was that of "a rich man who could commission an instrument exactly to his requirements". A similar situation can be recognized with the three Safavid Mecca-centred world-maps (see n. 17:5 below and also **VIIc**): there *either* the maker(s) had access to a copy of a 15th-century geographical table containing about 275 sets of coordinates from which they selected some 150 each time, but not always the same subset, *or* the maker of the original from which these copies were made had included already on his instrument a larger subset which guided (and restricted) the choice for the later instrument-maker(s).

[14] Alas there is for medieval European sources no equivalent to Kennedy & Kennedy, *Islamic Geographical Coordinates*. One could start a search for the sources of the English data by looking at the geographical table in MS Oxford Bodleian Bodley 68, fol. 39r: see already Gunther, *Early Science in Oxford*, II, p. 40. Notice that the medieval latitude values are far better than those that can be measured on the *Angliæ figura*, a map of the British Isles prepared *ca*. 1534-46 (London BM 130767—copy available at the British Museum giftshop).

[15] See n. 14:17. Note that Rudolf of Bruges in 1144 made an error of about 1/4° in his determination of the latitude of Béziers using an astrolabe (Lorch, "Rudolf of Bruges on the Astrolabe", p. 90).

particular (51;0°, 51;15°, 51;25°, accurately 51°04′) are somewhat confused. These data for cities in England were still in use on astronomical instruments in Elizabethan England.[16]

10 Universal horary dials in the German tradition

Some half a century ago Ernst Zinner discussed the different treatises from the German milieu, apparently mainly Vienna, dealing with the universal horary dial not in the form of a ship.[1] Unfortunately he did not question Gunther's classification of the Oxford *navicula* as German, so he got off to a very bad start, and two full pages later was still looking for an "Übergang von der Herstellung eines Venedigerschiffes zu der des Uhrtäfelchen Regiomontans".

Here a brief summary of Zinner's findings must suffice. The reader will have noted that one of the main problems associated with the English *navicula* is that it was clearly inspired by a device that was *not* in the form of a ship; yet the German tradition apparently post-dates the English tradition in which the ship-form predominates.

The earliest treatise, extant in four copies the earliest of which is dated 1434, is anonymous: the instrument described in it is illustrated in **Fig. 10a**. It is in the form of a circular disc, and does have a horizontal diameter; there is a double solar longitude/calendrical scale protruding below the disc. The side declination scale is not shown in the illustration and is not mentioned in the text. Zinner assumed that it was to be on the 12th-hour line. The *modus operandi* that he prescribes is that of the approximate solution advocated in modern writings on the *navicula*.

The Florence *navicula* (**Figs. 2c-d** and **Section 6c**), unknown to Zinner, is essentially of this kind with the empty space swept by the mast removed, and the lower declination scale is marked for the zodiacal signs on the front and the months of the year on the back. Also it lacks the necessary horizontal diameter. However, the solar scale on the universal horary quadrant on the back fixed at 52° argues against a German (*i.e.* Viennese) provenance.[2]

In 1457 Regiomontanus wrote on an *organum Ptholemei aut quadratum horarium*, the principle of which he himself stated that he had taken from an earlier author who does not sound like someone a couple of decades earlier: Regiomontanus refers to him as an *antiquus compositor*.[3] The instrument is now in the form of a rectangle with sights on the top and a shadow square in the lower right. The dial has a vertical declination scale on the right-hand 12th-hour line. A rotatable arm attached at the centre of the horary markings, with a cursor for setting the latitude, can move over a curved declination scale at the top. Unless there is some "fine tuning" with the bead on the thread, which is not mentioned by Zinner, the solution will not be accurate.

Zinner thought that one of a series of texts copied *ca*. 1471-86 and entitled *Organum ptolemei ad multas provincias* might be a complete or partial version of a treatise by Georg Peuerbach (1423-61) entitled *Extensio organi Ptolemei pro usu horarum germanicarum ad omnia climata*.

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16 Turner, *Elizabethan Instruments*, pp. 58-59, and pp. 148-149 of my review.
1 Zinner, *Astronomische Instrumente*, pp. 111-117.
2 See nn. 1:4.
3 On the sources of Regiomontanus' trigonometry see North, *Richard of Wallingford*, II, p. 31.

Fig. 10b: Regiomontanus' own illustration of his *Quadratum horarium generale* or *Uhrtäfelchen*. [From Zinner, *Astronomische Instrumente*, p. 114.]

←
Fig. 10a: The illustration of the universal horary dial in the 1434 treatise. The horizontal diameter is correctly present. The side declination scale is not shown and is not mentioned by Ernst Zinner in his description of this instrument. Note that the instrument is called an *organum*, and apparently the text indicates that this is because it resembles a musical instrument. [From MS Munich BSB lat. (= Clm) 5418, from the Zinner Archive, Institute for History of Science, Johann Wolfgang Goethe University, originally courtesy of the Bayerische Staatsbibliothek, Munich.]

In 1474 Regiomontanus presented his *Uhrtäfelchen*: see **Figs. 10b.** The earliest known example dates from *ca*. 1485, being attributable to the Benedictine monk Hans Dorn, who worked in Vienna and Buda: see **Figs. 10c-d**.[4] With Regiomontanus' splendid instrument, the

[4] #5524 = #8513—Bielefeld, Kunstgewerbesammlung der Stadt, Stiftung Huelsmann, inv. no. HW 97—see *Bielefeld Catalogue*, pp. 69-70 (no. 9).
For another example of Dorn's German see *London BM Catalogue*, pl. XXVIII (no. 207).

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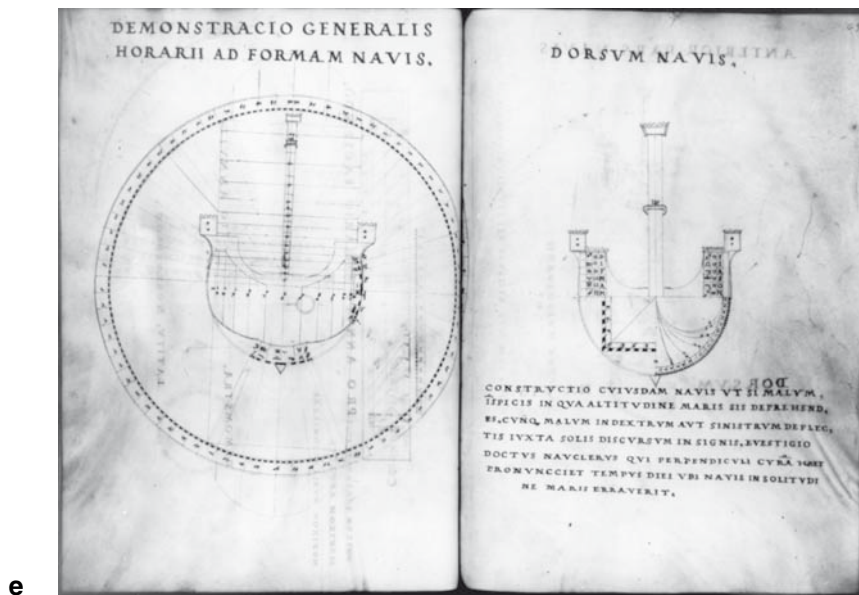
Fig. 10e: The 1527 copper-plate design of Georg Hartmann for the "universal hours" on a *navis*. It is significant that Hartmann drew the latitude markings as a set of horizontal parallels, suggesting that he realized that the bead would fall below the horizontal diameter when the latitude mast was rotated, and the latitude cursor would have to be restored to the appropriate parallel (in practice with an actual instrument this can be achieved using the bead). On the back are the standard universal horary quadrant and shadow square. [From MS Weimar, Thüringische Landesbibliothek, fol. max. 29, fol. 62v-63v, courtesy of the Ernst Zinner Archive, Institute for History of Science, Johann Wolfgang Goethe University, Frankfurt am Main.]

Figs. 10c-d: An *Uhrtäfelchen* from Vienna datable *ca*. 1485 (#5524 = #8513). This instrument is unsigned, but by virtue of the engraving and style, as well as by the kitchen German and unbelievable spelling mistakes, can be attributed to Hans Dorn, also known for two astrolabes, a celestial globe, a torquetum and a compendium. Missing from the front (c) is only the thread to be attached at the end of the *brachiolus*. On the back (d) is an horary quadrant for latitude [4]9;30°, hence the association with Vienna, rather than Buda, where Dorn also worked. (The inscription "*pollus 39 gr 30 m*" has previously led researchers to think that this piece was intended for use in Valencia.) Notice the shadow-scale, just inside the quadrant scale, serving base 1. This is an appropriate combination of universal and latitude-specific markings on a single instrument. See **Fig. XVII-5.2** for a newly-discovered astrolabe by Hans Dorn. [From *Bielefeld Catalogue*, pp. 69-70.]

problems of the bead sinking when the latitude arm is rotated are removed, and the need for any "fine tuning" is obviated for all time. This is achieved by means of a set of horizontal parallels for the latitude and a stiff *brachiolus* for supporting the thread and bead. The invention is Regiomontanus' and he deserves much credit for it, but he should not be credited with the invention of the *brachiolus*, for this is described in the treatise on the universal astrolabic plate by the 11th-century Andalusī astronomer Ibn al-Zarqālluh.[5] Whilst such a device is not found on any surviving Islamic examples of that instrument,[6] his treatise was known to Regiomontanus, who published his own treatise on it in 1534.[7]

In 1478 a monk Wilhelm, student of Peuerbach, also wrote or copied an earlier treatise on an *instrumentum generale* of this type but whose form is not clearly described. The author/copyist does, however, mention that some people use a *brachiolus* instead of a latitude arm.

There is an illustration of a *navicula* amongst the numerous copper-plate diagrams of instruments prepared by the early-16th-century Nuremberg instrument-maker Georg Hartmann: see **Fig. 10e**.[8] The illustration is beautiful in its accuracy and its simplicity: all of the necessary construction marks for the various scales are present. There appears to be some confusion, though, with the declination scale on the right-hand side, for the scale in the usual form of an arc of a circle smothers the 12th-hour line. But the fact that Hartmann appreciated what was involved is shown by the construction markings on the left-hand side. His illustration shows greater understanding than that of Orontius Finus in his *De solaribus horologiis et quadrantibus* ... (1560), who anyway had in 1524 constructed the side declination scale incorrectly on his ivory *navicula*.[9]

In his *Instrument Buch* published in 1533, Apian presented two different kinds of universal horary dial.[10] The first, called *horometro*, is a form of the Regiomontanus dial. The second, in the form of a quadrant called "*geuirtt*", "quartered" (?), or "*mit den geraden Linien*", "with straight lines", is a clever device apparently of Apian's own invention, in which the arguments on the latitude / declination scale above the hour-lines (now only one-half of a full set) have been switched (note that $\mathcal{G}(\Delta,\phi) = \mathcal{G}(\phi,\Delta)$): see **Figs. 10f-g**.

I deliberately refrain from pursuing the later development of the universal horary dial, mainly in the German-speaking world, but also in Flanders, France and elsewhere: such dials were very popular amongst those with the necessary skills to use them or the good taste to collect them. (Of particular interest is a dial made by Adrian Descrolières *ca*. 1570 for time-keeping by the sun and for eight individual stars, whose declinations are indicated by straight lines

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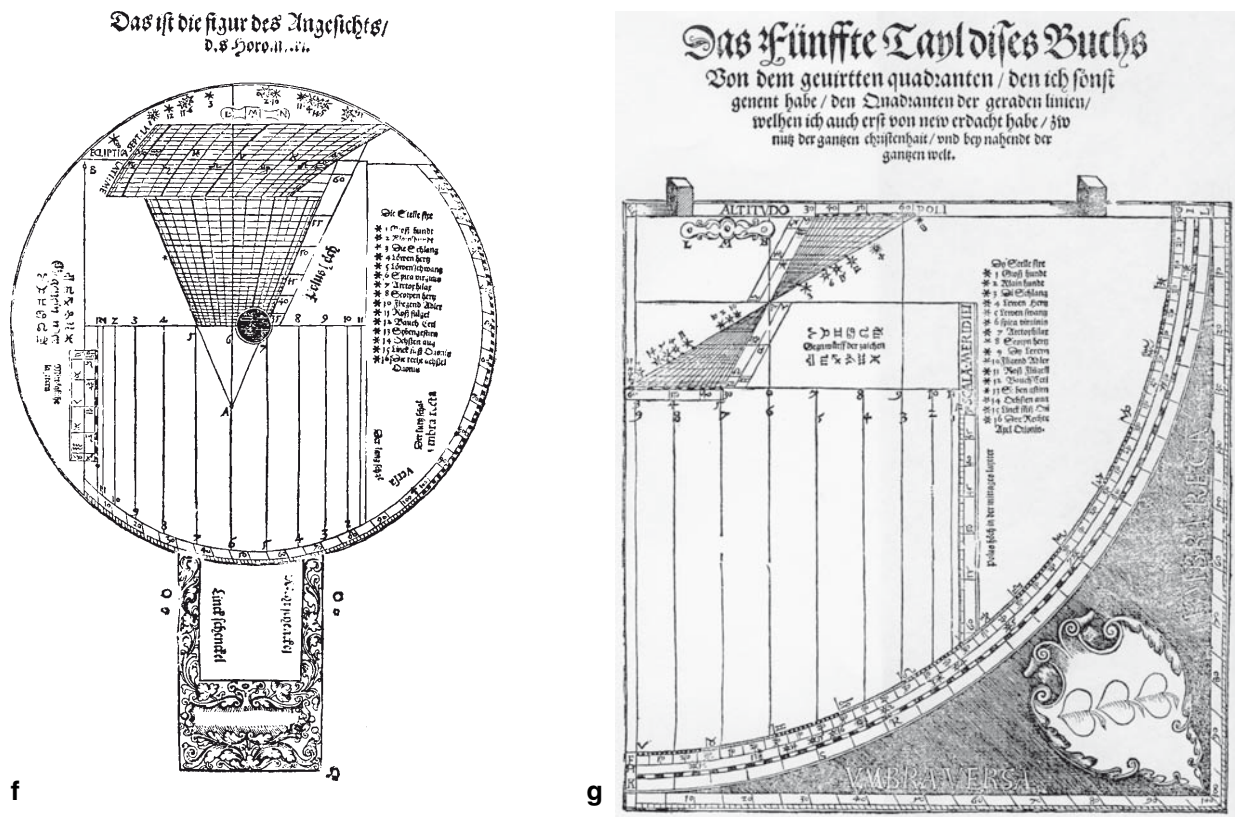
[5] See **XI-8.2**.

[6] See, for example, **Fig. X-5.2.3**.

[7] Zinner, *Astronomische Instrumente*, pp. 145-149, esp. 147.

[8] *Ibid*., pp. 111, 360-361, *etc*.; and Klemm, *Georg Hartmann*, p. 17, *etc*. These precious historical sources have yet to be properly published. Zinner's notes on the Weimar copy are in the Zinner Archive in Frankfurt (see n. 17:12).

[9] Illustrated, for example, in Brusa, "Navicelle", pp. 55-56 and figs. 5-6; also Archinard, "Cadrans solaires rectilignes", fig. 16 between pp. 176 and 177, and *eadem*, "*Navicula*", p. 92. On his ivory *navicula* see n. 3:14.

[10] Apian, *Instrument Buch*, (unpaginated), Pts. IV and V. On the latter, see Röttel, ed., *Peter Apian*, pp. 93-94.

Figs. 10f-g: The first and second horary dials proposed by Peter Apian in 1533. [From his *Instrument Buch*, Pts. IV and V.]

emanating from the centre of the horary markings.[11]) On the other hand, not a single universal horary dial is known from 16th-century England.[12] This is curious since the first dial of this sort appeared there out of the blue in the 14th century, in the form of the *navicula de Venetiis*. Perhaps this phenomenon is to be explained by assuming that the *navicula* was not an original product of the contemporaneous local scene but rather an import which was not fully understood anyway.

The related manuscripts have been identified and summarized by Zinner but remain unpublished and not studied again after his time.[13] A word of caution is necessary here, because there were two different instruments that bore the name *organum Ptolemei*: on the other one see **15**. And yet another such medieval device survives, albeit, as we shall see, as part of the

[11] Van Cleempoel, *Louvain Instruments*, pp. 203-204 (no. 68). An interesting variant to the Regiomontanus dial recovered from a ship-wreck is illustrated in Delehar, "Illustrations", pp. 388-389.
[12] Ackermann, "Instruments of Humphrey Cole", and G. Turner, *Elizabethan Instruments*.
[13] See n. 17:12 below.

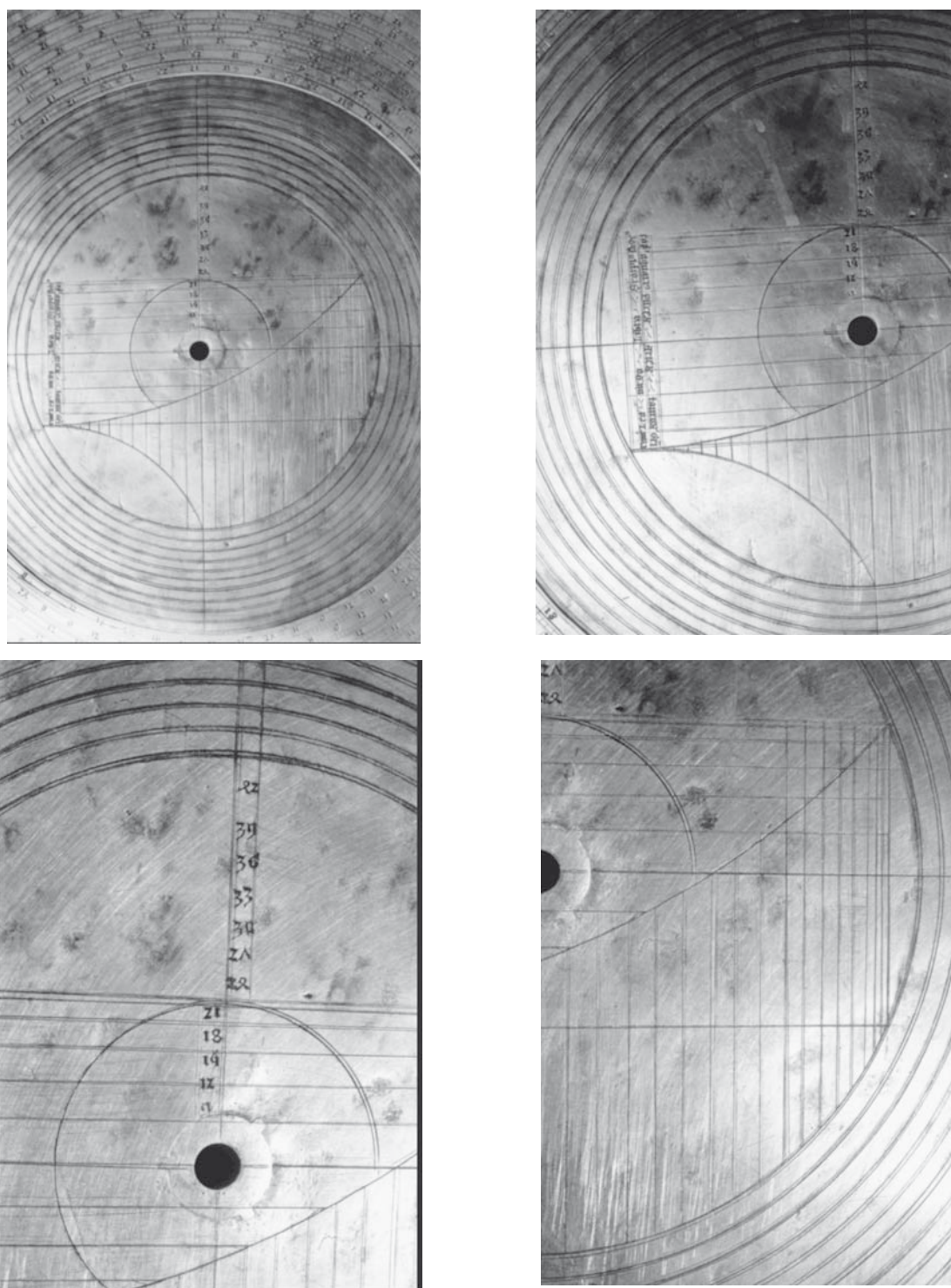



Fig. 10h: The universal horary dial on the back of the sole surviving example (#8507) of Richard of Wallingford's *albion*, made in Vienna *ca*. 1450. This is one of the most important surviving medieval/Renaissance instruments. It has never been studied, let alone published. See also North, *Richard of Wallingford*, III, pl. XXIII. [Photos by the author, courtesy of Marinella Calisi, Osservatorio Astronomico di Roma.]

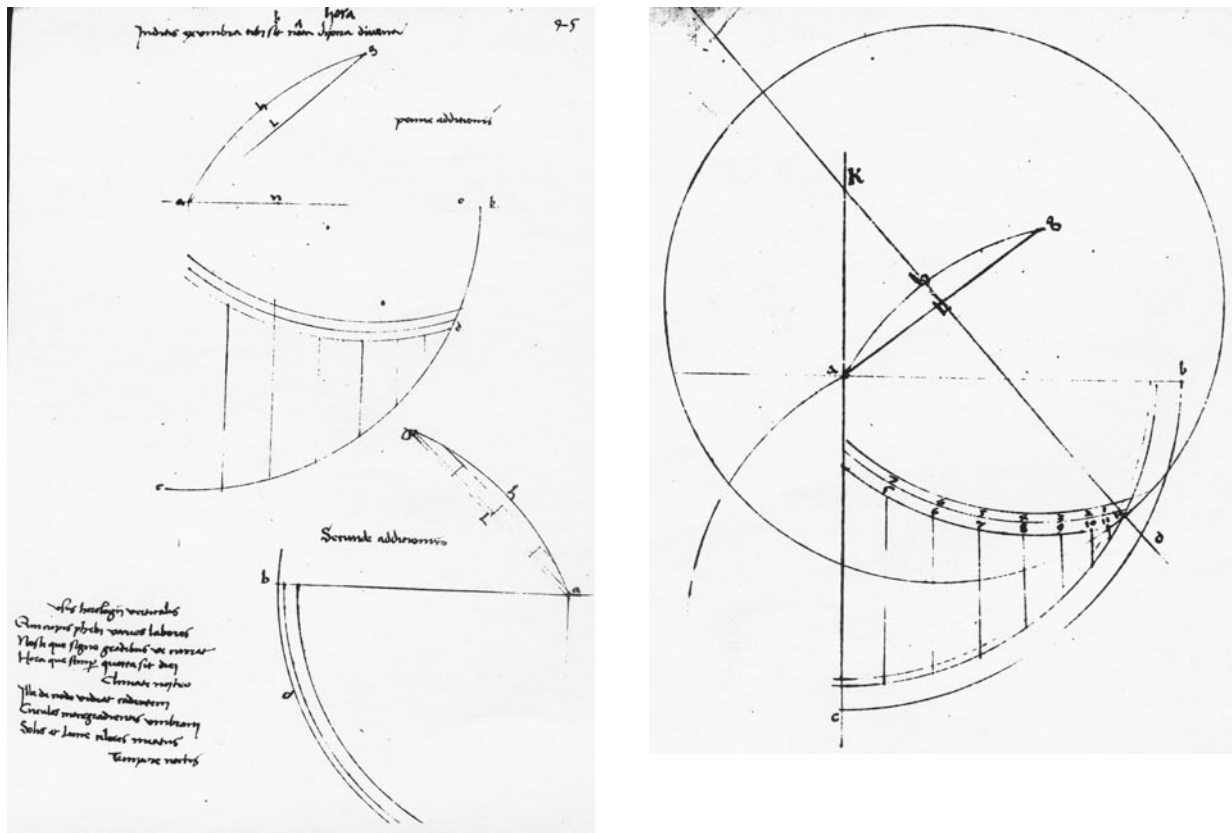



Fig. 10i: Diagrams of a similar nature in a manuscript of a treatise on astrolabe construction by Georg von Peuerbach *ca*. 1450. This treatise, along with all the other instrument texts of his predecessor Johannes von Gmunden, has never been properly studied, let alone edited and translated. [From MS Vienna Österreichische Nationalbibliothek 5176, fols. 45r-45v, courtesy of Professor Hermann Mucke, Vienna.]

markings on a 16th-century English instrument, perhaps not devoid of German influence: see **13**.

Was the English *navicula* tradition as known to Hartmann also known in Vienna in the mid 15th century? If so, it surely came from England. (Hartmann—and also Fine in Paris—includes the calendrical scale, although this is missing on the Florence *navicula*.) After all, the treatise on the equatorium known as the *albion* by Richard of Wallingford (*ca*. 1327) was translated by John of Gmunden in Vienna *ca*. 1430 and Regiomontanus also prepared an edition;[14] furthermore, the sole surviving example of an *albion*, inevitably unpublished, looks very much as if it was made in Vienna in the mid 15th century.[15] Indeed, on this very instrument there

[14] See North, *Richard of Wallingford*, II, pp. 130-134 and 134-136, on the manuscripts.

[15] On various other instruments from 15th-century Vienna see King, "Astronomical Instruments between East and West", pp. 183-188 (Appendix A: "Astronomical Instruments made in Vienna in the Fifteenth Century"), and on some of these King & Turner, "Regiomontanus' Astrolabe".

is a set of markings, incomplete as they stand, which constitute part of a universal horary dial on the only surviving *albion*. The instrument is apparently of mid-15th-century German (*i.e.*, probably Viennese) origin.[16] The markings—see **Fig. 10h**—are bounded by a circle; on the left is a vertical solar longitude scale, and by means of a family of horizontal lines this feeds the argument onto a uniform declination scale on the vertical diameter, which is extended beyond *ca*. 24° to *ca*. 50°. To the lower right of the solar scale a family of vertical horary markings, symmetrical with respect to the vertical diameter and bounded by two curious curves, sweeps across the lower half of the circle. One could reconstruct a movable component such as a swaying deck attached to the mast or a trigon, which would make the device functional, but not without some input on the part of the user. It is obvious we are dealing with some kind of horary dial and that at least the engraver knew what he was about. In order that we should understand these markings, maybe somebody should look at the relevant manuscripts: see **Fig. 10i**.

11 A late Islamic illustration of a universal horary dial

In one late Islamic source we find an illustration of a universal horary dial for determining time from solar altitude for all latitudes (**Fig. 11a**). This is in MS Cairo MR 40,2, fol. 45v, copied in Istanbul in the year 1160 H [= 1747] by Muṣṭafā Ṣidqī ibn Ṣāliḥ (d. 1769).[1] The instrument, labelled simply "*mustaṭīl*", that is, "rectangle" or "rectangular (device)", is illustrated along with some 20 others (fols. 40v-64r) relating to the construction of sophisticated astronomical instruments, some of which are in the early-14th-century Syrian tradition associated with the Aleppo astronomer Ibn al-Sarrāj.[2] The diagram shows no obvious traces of possible European influence beyond, one might say, the *brachiolus*; however, it is not

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[16] #8507—Osservatorio astronomico di Roma—unpublished (!), unfortunately omitted from my overview of instruments from 15th-century Vienna (see the previous note). See already the illustrations in North, *Richard of Wallingford*, III, pl. XXIII, although this instrument seems to be nowhere mentioned in the text of North's book. North correctly noted that the markings were "incomplete" and "non-standard".

[1] See *Cairo ENL Catalogue* (in Arabic), I, pp. 439-446, for a list of the contents of the two precious volumes copied by Muṣṭafā Ṣidqī, namely, MR 40, copied in 1160 H [= 1747], and MR 41, copied in 1153 H [= 1740/41]. Altogether these two volumes contain 55 astronomical and mathematical treatises, many of which are of are by 10th-century Muslim scholars (such as Abū Sahl al-Qūhī and Thābit ibn Qurra), sometimes based on Greek originals, and not a few of which are unique copies. Where later authors are involved the works are of considerable historical interest, such as a treatise on geometrical problems by Ibn al-Sarrāj (see n. 11:2) and some original Ottoman works based on Greek originals (on some of these see Berggren, "Archimedes among the Ottomans"). Although the name Ṣidqī could be taken as being Egyptian, it seems that Muṣṭafā Ṣidqī worked in Isṭanbul: see further *Cairo ENL Survey* (in English), p. 112 (no. D81, incorrectly listed under Egyptian authors), and İhsanoğlu, ed., *Ottoman Astronomical Literature*, II, pp. 466-467 (no. 308). There is no indication in the two manuscripts of this other than the fact that some of the diagrams of instruments are specifically drawn for latitude 41°, that is, Istanbul. See also *Cairo ENL Catalogue*, I, pp. 559-560, for the contents of another manuscript (MS ṬJ 635) copied by Muṣṭafā Ṣidqī in 1170 H [= 1756/57], this containing eleven mainly late mathematical treatises. See Charette, "The Library of Muṣṭafā Ṣidqī", forthcoming, on manuscripts copied by or owned by Muṣṭafā Ṣidqī.

[2] See King, "The Astronomical Instruments of Ibn al-Sarrāj", first published in *idem*, *Studies*, B-IX, and now **XIVb-5**, also Charette, *Mamluk Instrumentation*, on Ibn al-Sarrāj's contemporary, Najm al-Dīn al-Miṣrī of Cairo. More information is in Charette & King, *The Universal Astrolabe of Ibn al-Sarrāj*, forthcoming.
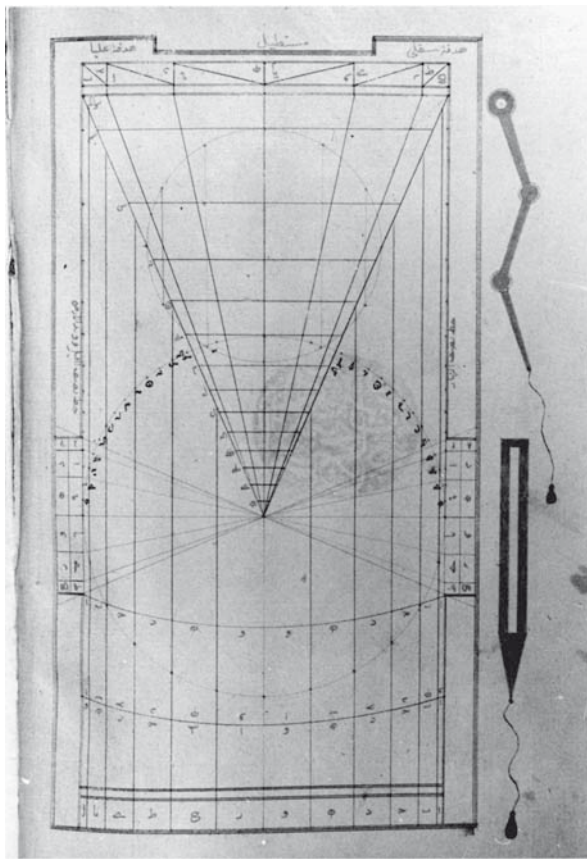
Fig. 11a: The universal horary dial illustrated by Muṣṭafā Ṣidqī in 1747. The illustration gives every impression of being of an Islamic instrument, down to the implicit use of the parameter 23;35° for the obliquity of the ecliptic. [From MS Cairo MR 40,2, fol. 45v, courtesy of the Egyptian National Library.]
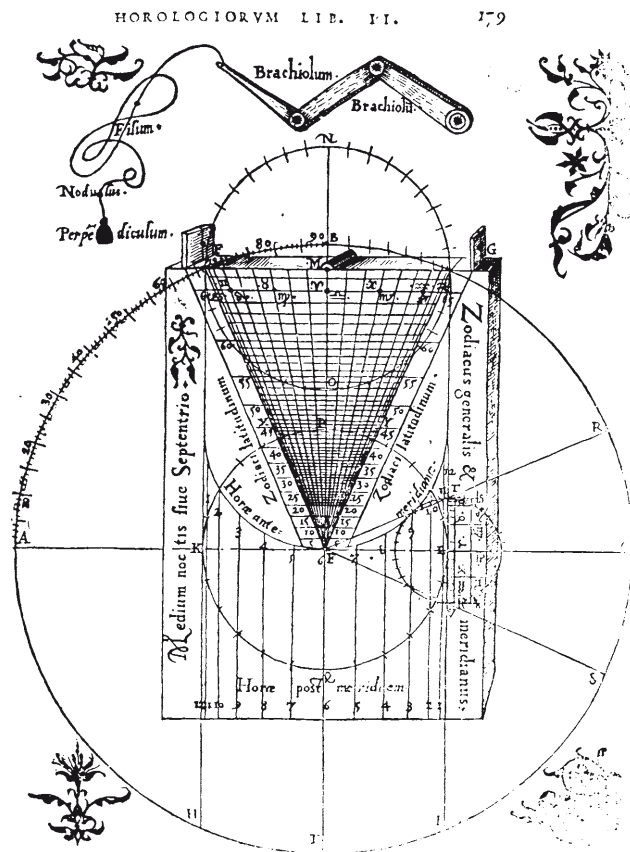
Fig. 11b: The universal horary dial illustrated by Oronce Fine in 1560. [From *Linton Collection Catalogue*, p. 23.]

generally known that the *brachiolus* (to serve a universal astrolabic projection) was invented in 11th-century al-Andalus. Indeed, there are several features which would argue for an Islamic provenance, for example, the implicit use of 23;35° for the obliquity of the ecliptic: this is an Islamic value popular between the 9th and 12th centuries, which, as far as I know, was not used in Islamic astronomy after the 15th century.[3] It is highly unlikely that Muṣṭafā Ṣidqī himself invented the device, for if this were the case one might reasonably expect a description of its *modus operandi* (but there is none for any of instruments featured in the illustrations).

Certainly the similarity between the markings and those of the printed Regiomontanus tradition is remarkable: see, for example, the illustration of Oronce Fine is his *De solaribus*

[3] See n. 4:5 above.

horologiis, & quadrantibus libri quatuor (Paris, 1560) in **Fig. 11b**.[4] But before taking it too seriously we should remember that Regiomontanus made no claim to have invented his device (see **10**). And before dismissing the possibility that this illustration may have been inspired by those of Regiomontanus or Oronce Fine, we should keep in mind that Muṣṭafā Ṣidqī translated from French to Turkish a book by Nicolas Bion on astrolabes (1710).[5] In his illustrations he also included an astrolabe rete taken from an astrolabic clock by Paul Braun of Augsburg *ca*. 1600.[6]

12 Ḥabash's universal instrument for timekeeping by the stars

Now Ḥabash designed a highly complex universal computing device for timekeeping by the stars (see **Figs. 12a-d**). Whilst we have no information that would lead us to suppose that this instrument was ever made by any later astronomers, Muslim or European, it is clear that the text as preserved in the unique 13th-century manuscript now in the Bodleian Library in Oxford has suffered at the hands of successive copyists. Ḥabash's treatise on this instrument has now been published with an English translation by Francois Charette and Petra Schmidl.[1] Their commentary is restricted to the construction of the instrument, for its use is not mentioned in the incomplete text and is by no means self-evident. Furthermore, it seems that even the text on the construction may not be complete, so that we may be missing a description of a key part of the instrument.

It is, however, clear that the instrument serves to find for any latitude first the time from an observed stellar altitude, and also the azimuth of the star (which, of course, could also be observed). But, as we shall see, it also achieves something more. Thus the instrument is inevitably more complicated than the universal horary dial for timekeeping by the sun and, necessarily, has a different morphology. Nevertheless Ḥabash's device has in common with the early European universal hour dials the following features:

(1) a latitude scale based on $\tan \phi$;
(2) a movable cursor within a scale;
(3) a scale showing $\delta(\lambda)$; and
(4) parallel markings for the sine function (actually three sets !).

In addition we note the presence of:

(5) a mechanical device to insert the auxiliary function $\max \mathcal{E} = \sin \max d(\phi) = \tan \varepsilon \tan \phi$.

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[4] *Linton Collection Catalogue*, pp. 22-23 (no. 33).

[5] İhsanoğlu, ed., *Ottoman Astronomical Literature*, II, p. 466, no. 308, item 3; also King, *Mecca-Centred World-Maps*, p. xxix.

[6] See King, *Mecca-Centred World-Maps*, p. 353, n. 101, also p. xxix. As noted in the first reference, this German rete is used to decorate the cover of the ill-fated journal *Arabic Science and Philosophy*.

[1] Charette & Schmidl, "Ḥabash's Universal Plate". The influence of successive copyists is best seen in the tables, although reconstruction of many entries was facilitated by the fact that Ḥabash's original entries were very carefully computed. Ḥabash's tables for constructing the melon astrolabe presented in Kennedy & Kunitzsch & Lorch, *Melon Astrolabe*, shared the same fate in the manuscript tradition and I suspect that further investigation would establish that they originally looked better than they look now.
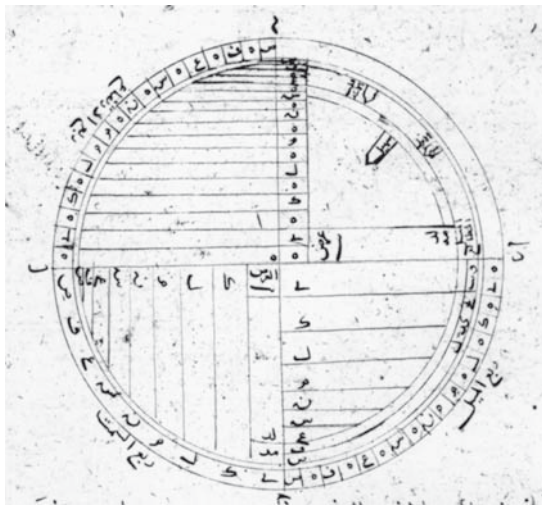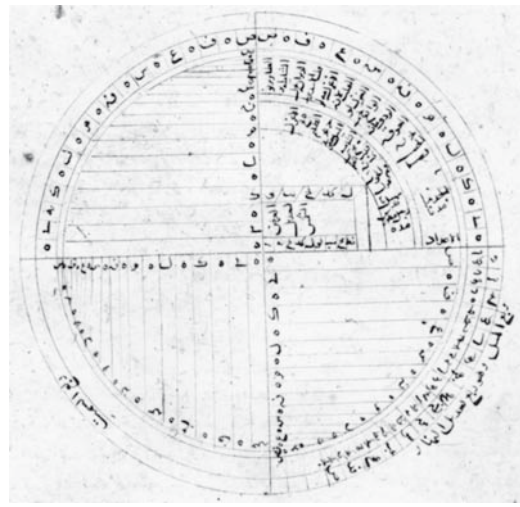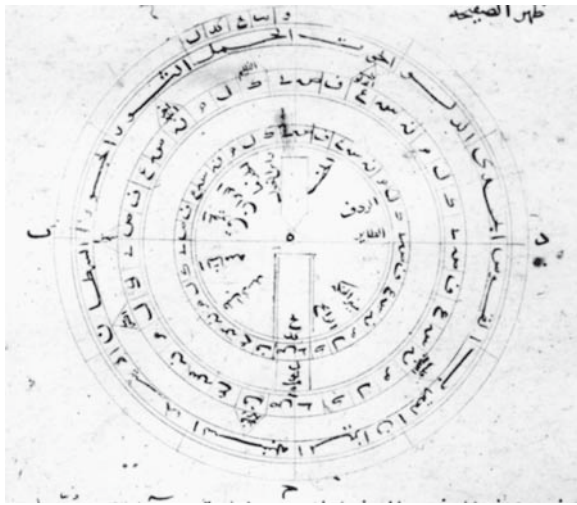
Fig. 12a-d: The main components of Ḥabash's universal dial for operations with the stars. The top two extracts show the trigonometric markings on the front of the instrument (illustrated twice to show all the markings). On the lower left is shown the back of the instrument with the ecliptic and equatorial scales on the outside and the small movable plate that can be displaced from the centre in order to provide a device for showing oblique ascensions for any latitude. On the lower right is one of the two alidades, this one having both a uniform 0-90 scale and a non-uniform 0-60 sine scale. [From MS Oxford Bodleian Marsh 663, fols. 243, 246, 245 and 247, courtesy of the Bodleian Library.]

To find the time t* before or after midnight from the altitude of a star with declination Δ and right ascension α observed at altitude h in a locality with latitude ϕ when the solar longitude is λ, one needs the equivalent of the formula in **5** with the stellar declination Δ substituted for the solar declination δ. Once t* has been found, the azimuth a can be found by one of several procedures. But what was important in Islamic timekeeping, now in the service of astrology rather than religion, was not only to know the time but also to know the longitude of the

horoscopus, that is, the point of the ecliptic simultaneously rising over the ecliptic, λ_H.[2] To find this, one needs to know the hour-angle t* and the longitude of the sun λ, and to have some facility with right and oblique ascensions.

Any attempt to reconstruct the use of the various parts of this instrument must be provisional failing the original text. Since only quadrants are available on the instrument (three in number) and not a complete semicircle of markings (as on the universal horary dial of the *navicula*), I shall assume that the versed sine function (which has arguments from 0° to 180°) is not to be used. I shall also assume that the reader is familiar with the basic operations with the sine quadrant, as explained recently by Richard Lorch on the basis of a 9th-century Arabic text:[3] these include the calculation of Sines and Cosines and the corresponding arcs, as well as the calculation of products and quotients of Sines and (Co)sines. For simplicity, I shall keep the base for trigonometric functions as unity and ignore signs. Yet keeping control of the various cases governing the directions of some of the quantities involved in the sequel would have been a challenge to even the best of the Muslim astronomers.[4]

Given that one has measured the altitude of a star h with declination Δ on a day when the solar longitude is λ and the solar declination δ, a hypothetical *modus operandi* would be the following. First, we use a sine quadrant on the front of the instrument to compute $\sin h \bullet \mathcal{G}(\Delta,\phi)$ and $\mathcal{E}(\Delta,\phi)$. Then their algebraic difference is $\cos t(h,\Delta,\phi)$, whence from the same quadrant we can find t* (measured from midnight). Second, we use a sine quadrant to compute $\mathcal{K}(h,\phi)$ and $\mathcal{L}(\Delta,\phi)$. Then compute $[\ \mathcal{K} \sim \mathcal{L}\ ] / \cos h$, which is $\sin a(h,\Delta,\phi)$, whence also a.[5] Third, move the centre of the small plate on the back of the instrument from the centre of the larger plate beneath it by the amount $\max \mathcal{E} = \sin \max d(\phi)$, using the scale provided, to produce some kind of means of displaying oblique ascensions $\alpha_\phi(\lambda)$ for any latitude.[6] It is at this point that I am no longer able to explain the further uses of the instrument, for the available components do not apparently suffice for achieving what I would like to see as its ultimate purpose. Somehow I would have liked the ensemble to display the instantaneous configuration of the sun, the star and the ecliptic with respect to the meridian, so that one could read off the longitude of mid-heaven, λ_M. By virtue of the well-known relation:

$$\alpha_\phi(\lambda_H) = \alpha'(\lambda_M) ,$$

if it was clear that we could read oblique ascensions for any latitude, one could then easily determine λ_H.[7]

One may well ask what, if any, is the advantage of this instrument, if I have interpreted part of its function correctly, and supposing one could further use it to find the ascendant for any

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[2] See the articles "Ṭāliʿ" [= ascendant] and "Maṭāliʿ" [= ascensions] in EI_2, as well as n. 5:13.

[3] See Lorch, "Sine Quadrant".

[4] These are all laboriously itemized by the 10th-century Cairo astronomer Ibn Yūnus for this and all other operations of spherical astronomy: see King, *Ibn Yūnus*, *passim*.

[5] In spite of the inclusion of a procedure for determining the azimuth, there is apparently no intention to solve a favourite problem of Ḥabash, namely, to determine the time since rising for the sun or a star to attain a particular azimuth. On this see Kunitzsch & Lorc, "*Maṭāliʿ al-samt*".

[6] On ascensions see n. 4:3.

[7] See n. 5:13.

latitude from a stellar observation, over the standard astrolabe? First, with the astrolabe one is restricted to the latitudes for which there are plates; here the operations can be performed for any latitude. Whether the device is more effective than a universal astrolabe[8] is debatable. The disadvantages of the instrument are more obvious. First, the data and scales on the instrument are very susceptible to errors that would render them useless. The data are in fact so complicated that only mass production of an approved proto-type makes any sense: our over-optimistic Ḥabash was way ahead of his time. Second, there are several calculations involved in merely setting up the instrument for use. These would have been second nature to Muslim astronomers from the 9th century onwards, but still, one slip and ... . Without such slips one could hope to find the horoscope to within a degree or so, whereas with calculation all the way one could find it to within a few minutes. We are dealing, in fact, with a rather unsatisfactory combination of a calculating device and an analogue computer device, which is aesthetically pleasing neither from a purely mathematical nor from a purely astronomical point of view,[9] but certainly has some very ingenious features.

There is one feature of the instrument as illustrated in the Oxford manuscript that still defies explanation. This is the scale to the upper right of centre on the front plate. It consists of a horizontal scale 0-30 at a distance of Sin 20° above horizontal radius (taken as 60), which itself bears a scale 0-54. This is not menioned in the text and bears a mysterious caption *al-ʿarḍ li-taʿdīl al-shams*, "the latitude for correcting, or for the equation of, the sun", which makes little sense. It was tempting to modify the last word to *al-samt*, for *taʿdīl al-samt* is a name given to the auxiliary function $\mathcal{K}(h,\phi)$.[10] But this makes no sense either. On the other hand, the first scale could be for measuring, for a very limited range of solar altitude, shadows to base Sin 20° ≈ 20.5 ≈ $^1/_3$R, a base we also find in use in Aleppo in the 14th century, though again without any explanation beyond that it keeps operations with the bead and thread on the surface of the quadrant rather than having them extend beyond the outer rim.[11]

13 A remarkable English instrument fitted with a universal horary dial

An English instrument, known to Gunther and dutifully described by him with great care but never studied since, bears some markings that are relevant to our study.[1] The instrument is

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[8] See n. 3:2.

[9] The same problem besets operation with the medieval European instrument with a *quadrans novus* on the front and a sexagenarium on the back. The front can only be used to find the time approximately; to find the time accurately, one must perform calculations from scratch with the trigonometric grid on the back.

[10] Charette & Schmidl, "Ḥabash's Universal Plate", p. 155 *ad* Fig. 5.

[11] See Charette & King, *Universal Astrolabe of Ibn al-Sarrāj*, to appear.

[1] #8501—Oxford, Museum of the History of Science, inventory no. 26323 (formerly St. John's College, Oxford)—see Gunther, *Early Science in Oxford*, II, pp. 135-140 (no. 56), especially the illustrations between pp. 136 and 137, King, *Mecca-Centred World-Maps*, p. 352; and Meliconi, "Brechte Plate", on website EPACT.

The instrument is not featured (or even mentioned) in Turner, *Elizabethan Instruments*, in spite of the fact that it is Elizabethan, but when compared with Turner's instruments, it sticks out like a sore thumb. The "overview" of this instrument on the website EPACT reads as follows (and does not relate to the associated, more careful, "detailed description" by Maria Meliconi):

medieval in style and inspiration, as well as engraving (**Figs. 13a-d**). However, there can be no doubt that the inscription "ROGER BRECHTE 1527",[2] together with a distinctive personal symbol, typical of German "*Hausmarken*" or "*Steinmetzzeichen*",[3] relates to the maker of the instrument and his date. Certainly the instrument was made for use in England for, as noted already by Gunther, one side bears calendrical scales featuring some saints particularly favoured there; also, as we shall see, some of the markings are specific to a latitude in England. The style is fully medieval, rather than Renaissance, and the inscriptions, both letters and numbers, have Gothic forms.[4]

The complex set of markings on the other side consists of the following:

(1) Upper middle—a universal horary dial, with a slotted radial rule (fitted perpendicular to an alidade with no further scales) bearing a movable radial cursor that can rotate over a family of circular latitude markings for each 3° bounded on each side by a V-shaped frame with vertex at the centre, on both arms of which there is a latitude scale marked for each 2° up to 66° and labelled for each 10° up to 60°. There are three solar declination scales, one on each side at the circumference (only the one on the left is fully marked) for the zodiacal signs, the other above at the circumference, marked for the months. There is a full circle of labelled vertical horary markings about the centre. In addition there are two vertical altitude scales on either side of the main markings, forming the sides of an M-shaped frame.

(2) Entire surface—stereographic projections of the equator and solstices (winter on the outside, summer on the inside, as on an astrolabe); circumferential scale divided for each 5°, subdivided for each 1°, and labelled for each 15° (equinoctial hours) on the left and upper right and for each 10° in the lower right.

(3) On either side of the main horary dial (1)—two vertical scales. The one on the right is clearly for southern declinations and runs from 0° to 24° in 2°-intervals with labels 8-14-20. This scale is to be associated with another perpendicular to it on the horizontal diameter

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"Astrological Instrument. Signed by Roger Brechte. Dated 1527; German (?) Copper; 225 mm in diameter. This is perhaps more an astrological than an observational instrument. It has all of the necessary features for observation, such as an alidade and degree scale, but also all that is needed for correct astrological and calendrical predictions, such as the indications of dominical letters and astrological houses. On one side of the instrument there is a Regiomontanus-type dial, though useless without an arm. It is not clear whether the arm is presently missing, or the instrument is incomplete, or the engraved lines were meant to have another aim than a sundial."

There is a general tendency to dismiss any instrument one does not understand as a fake or as "astrological". In this case, the author of this short description has chosen the latter, but I hasten to point out that the astrological houses are not featured (nor could they be).

[2] The name Brechte (related to English Bright) appears to be German (rather than, say, Flemish or Dutch), and the more common form Brecht is Southern German. In current telephone directories for Munich, Augsburg, Ulm, and Stuttgart the name Brechte is not attested, but there are, respectively, 24, 4, 2, and 25 entries for Brecht. On the other hand, Brechte is a female Old Dutch Christian name. Furthermore, Roger is not a German name, and attests to a French or Flemish connection. See also n. 13:13.

[3] On these see most recently King, *The Ciphers of the Monks*, App. E3 on pp. 324-334, with extensive bibliography, and on this one in particular, p. 329.

[4] On my use of this term see *ibid*., p. 28, n. 1.

that is also marked for each 2° of northern declination (the groupings of each 8° in the middle are unfortunately grouped). On the left is a scale divided similarly to the first labelled (from the top) 18-24-30-38, so that the span is 14-38. The scale thus serves the meridian altitudes for latitude 52°. There is another horizontal scale associated with this one too. All of these scales are to be used in association with the ecliptic scale (4) if one wishes to determine $\delta(\lambda)$ or $H(\lambda)$.

(4) Lower left—a pair of arcs representing a stereographic projection of the ecliptic within a quadrant. The "main" arc is that for the southern signs, extending from the equinox on the horizon for 52° to the outer circle for the winter solstice. The arc for the northern signs has been folded over from its "dummy" counterpart above the horizontal diameter. This "ghost" ecliptic, which in facts extends over the other three-quarters of the entire surface is labelled in a somewhat maladroit fashion, once in each of the three quadrants: *lūā* (?) *eclipt*[9], *via solis*, and *via solis lunīē* (?) *eclipt*[9].

(5) Lower left—a family of stereographic seasonal hour curves for latitude 52°, starting at the horizon for 52° on the left and ending with the meridian on the vertical radius, and between the solstitial circles across the ecliptic scale (4).

(6) Lower left near centre—a shadow square (base 12).

(7) Middle right—a family of stereographic projections of horizons for various latitudes between the solstitial circles. These are served by the ecliptic scale (4).

(8) Lower right—a universal horary quadrant for *seasonal* hours. These could be served by the ecliptic scale (4), but it is simpler (and more in the spirit of the original purpose of the markings) to enter the meridian altitude from the scale (3). There are problems with the markings: see below.

(9) Lower right—horary markings for the *equinoctial* hours and a stereographic solar longitude scale for a latitude of 52°. These are also served by the ecliptic scale (4).

Note that Brechte has provided *three sets of universal markings* in the form of the univeral horary dial (1), the horizons for different latitudes (7), and the universal horary quadrant (8); and *three sets latitude-specific markings* for latitude 52°, namely, a scale for meridian altitudes (3), a quadrant for the seasonal hours (5), and a quadrant for the equinoctial hours (9). The combination of these markings on a single plate, not attested elsewhere, is at first sight nothing other than brilliant. On closer inspection, however, we detect some problems, some more serious than others.

The dial (1) is of the same kind as that on the *navicula* according to the construction in the available medieval texts. Thus the device appears to work only approximately. If it had been properly assembled with the side declination scales in the right place, and with a little "fine tuning", here involving a thread with bead delicately hooked over the nipple on the cursor, it would have worked perfectly. Gunther observed a similarity with the *Horarium generale* of Johannes Stöffler (at the end of his 1518 *Calendarium Romanorum*), repeated in various later works, including those of Oronce Fine (*De gli oriuoli*).[5] I have not been able to confirm this.

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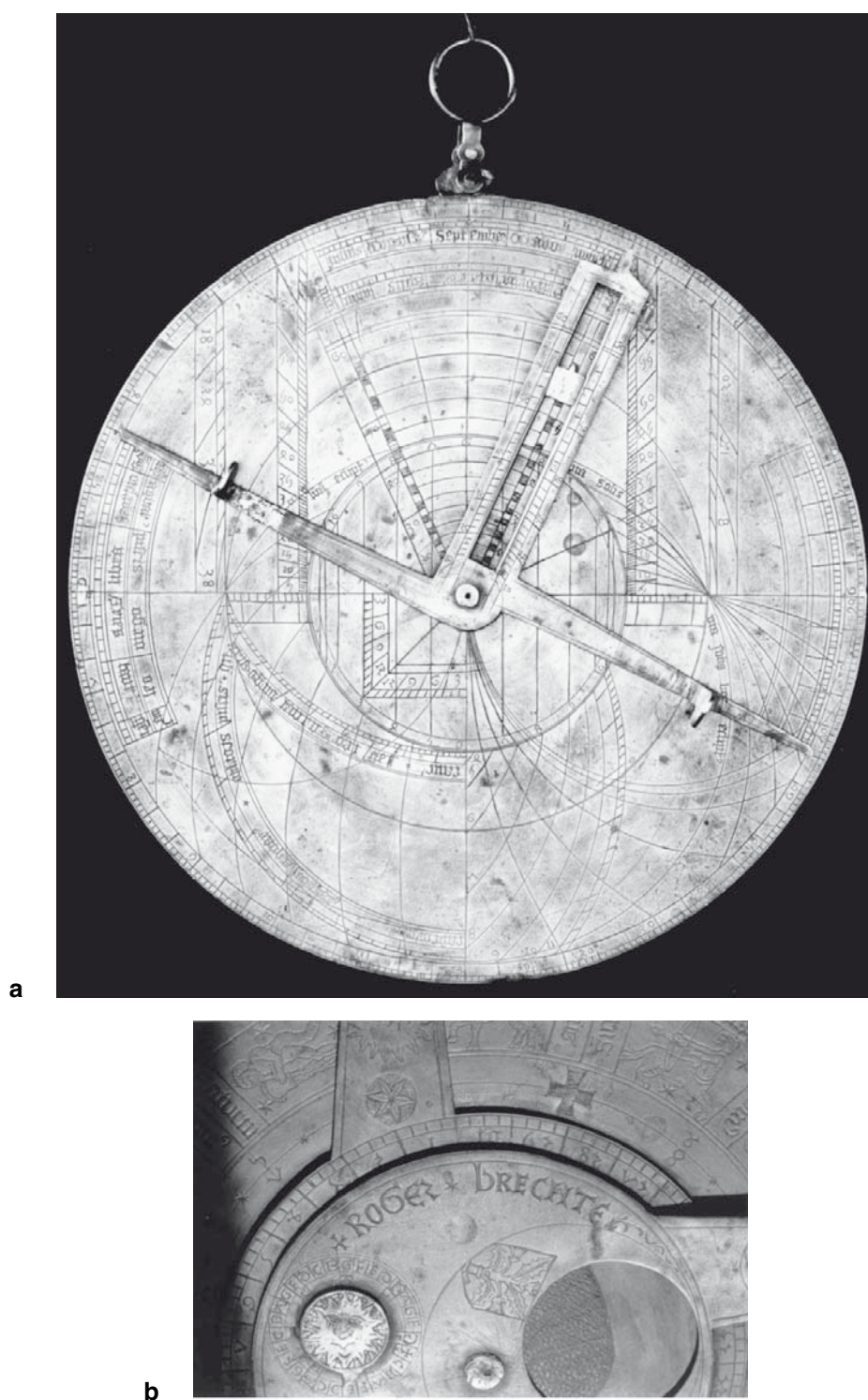
[5] Gunther, *Early Science in Oxford*, II, p. 136.

Figs. 13a-d: The front and back of the astronomical plate by Roger Brechte (#8501), with details of his signature and owner's mark. [Originally property of St. John's College, Oxford, two photos by the Museum of the History of Science, Oxford, two details by the author, courtesy of the Museum.]

c

d

It was quite ingenious to "stretch" the declination and meridian altitudes scales (3) in this way. The declination is of course measured radially, here the scales have been extended in length and potential accuracy by rotating them with respect to the radius. This was surely not inspired by considerations of space. I know of no parallels to these "stretched scales" in medieval or Renaissance instrumentation.

The seasonal hour markings on (5) call for some comment. They correspond to the seasonal hours *above* the horizon. (On the standard astrolabe plate one finds markings only *below* the horizon, so as not to interfere with the more important altitude and azimuth markings above the horizon.[6]) No other instrument with such markings comes to mind. But there is a problem: there is no way to enter either the altitude (or the azimuth), so that the seasonal hour markings are quite useless as they stand.

Also the seasonal hour markings on (8) do not withstand close scrutiny. Those for the 6th and 5th/7th hours are drawn to arguments 90° and 75° on the *outer* rim of the outer scale. The remaining arcs have been drawn to the arguments 60°, 45°, 30° and 15° on the *inner* rim of that scale. All is not well here.[7] The markings for the seasonal and equinoctial hours in (8) and (9) are not stereographic, but rather graphic representations of mathematical functions on a stereographic background: the altitude is to be entered on / read from the outer scale. The subdivisions of the solar declination scale situated between the 11th and 12th equinoctial hour curves are, however, problematic.

There are some additional markings whose purpose is not clear to me. These are:

(10) On the "seasonal hour quadrant" (4+5) there are two cusps starting from a point on the prime vertical. The upper one is an arc of a radial semicircle extending from the centre of the entire dial, so this defines the point of intersection with the horizon. If it were part of the stereographic projections, it should surely go only as far as the inner circle for the summer solstice. Perhaps it was intended to serve a purely trigonometric function, in which case it should be a complete semicircle reaching as far as the outer circle for the winter solstice.[8] The lower one runs concentric with the circle for the winter solstice as far as the meridian on the vertical diameter, as if it represented the declination circle of some celestial body, in fact, $\Delta = -20°$. I am at a loss to explain why these markings are present and what purpose they might serve.

With the possible exception of the universal horary dial (1), I would maintain that each and all of the items (2-9) on this side of the plate were invented in 9th- or 10th-century Baghdad. I have previously argued that the representation of the entire ecliptic as two arcs within a quadrant, such as found on the *quadrans novus* of Profatius *ca*. 1290 and also as item (4) on the Brechte plate, is a European innovation. But now we know that it appeared on the astrolabic

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[6] The arcs of circles used for such markings are approximations to the far more complicated curves that would display the seasonal hours accurately. See Hogendijk, "Seasonal Hour Lines on Astrolabes and Sundials".

[7] If one must combine universal markings for the seasonal hours and latitude-specific markings for the equinoctial hours, then let the result be as illustrated in Michel, *Traité de l'astrolabe*, p. 85.

[8] See **XI-11.3**.

quadrant already well known in 12th-century Egypt,[9] and furthermore the astrolabe with a crescent-shaped ecliptic (of which the markings on these quadrants constitutes one-half) was described by al-Sijzī in the late 10th century.[10] However, here it appears not with a set of altitude circles for a specific latitude, but rather with a set of curves for the seasonal hours, which, as we have already noted, serve no purpose as they stand.

I would contend that this instrument by Brechte is entirely medieval in its conception, or, to put it another way, that Brechte copied it from a medieval instrument, not all of whose functions he understood. Even the throne is reminiscent of European astrolabes several centuries earlier.[11] The basic problem with this instrument is simply that it was made in England in the early 16th century, when astronomical instrumentation had taken off in new directions with a decidedly Renaissance flair, albeit still traditional and with no real technical innovations that are not known from earlier instrumentation.[12] Who was this Brechte? As this book goes to press, I have not been able to determine whether he was, for example, part of the Oxford scene of his time.[13]

To summarize, we have here a variant to the universal horary dial on the *navicula* which —with various qualifications—functions in precisely the same way, but can be also used for stars within and not too far outside the two solstitial circles. The upper central parts of the circle of horary markings are superfluous. Remove them and one is a step closer to the markings in the German manuscript tradition (**Fig. 10a**) and also to the *navicula*.

14 Early Islamic predecessors to the European universal horary dial?

May I be forgiven for searching the available sources in an attempt to find some medieval soul who was clever enough to invent the universal horary dial. As far as we known from the sources currently available, there was no milieu in medieval Europe for the invention of the horary markings of the *navicula*; the invention of such a device was not only outside the capabilities of the vast majority of medieval European astronomers, but also their interests lay elsewhere. We are therefore entitled to look elsewhere for the origins of the universal horary dial on the *navicula*, and, in my opinion, the most likely place is 9th-century Baghdad. Since there is not a trace of this device as such in the known *early* Islamic sources, I may perhaps be permitted to grasp at some straws.

In a 10th-century source we find mention of a device for timekeeping of which we have only the name: *lawḥ (al-sāʿāt)*, "board (for finding the hours)" (or, if I may, "*Uhrtäfelchen*"). This

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[9] See **X-6.4** and **Fig. X-6.4.4**.

[10] MS Istanbul Topkapı Ahmet III 3342, fols. 123r-153v + 114r-122v, copied in 634 H [= 1236/37] (see King, al-Khwārizmī", p. 21). An edition and English translation have been prepared by Richard Lorch (as yet unpublished).

[11] See Stevens *et al*., *Oldest Latin Astrolabe*, Figs. 1-2, also in **Fig. XIIIa-9.1a**; Gunther, *Astrolabes*, II, pls. CXXVI opp. p. 463, and CXXVII opp. p. 477; also King, "Earliest European Astrolabe", figs. 3, 12, 13, 18a and 18b, and *idem*, *The Ciphers of the Monks*, pp. 373-374, and 402-403.

[12] See n. 9:16.

[13] He is not mentioned in the 1st edn. of the *Dictionary of National Biography* and I have not seen the 2nd.

occurs in the encyclopaedia of Abū ʿAbdallāh al-Khwārizmī (not to be confused with the astronomer Abū Jaʿfar al-Khwārizmī).[1] After mentioning varieties of astrolabes and before mentioning the armillary sphere, he asserts:

> "The instruments for finding the hours are many, for example, the water-clock (*al-ṭarjahāra*); the box for the hours (*ṣandūq al-sāʿāt*) [probably a mechanical device]; the ... [??] for the hours (*dabbat al-sāʿāt*) [likewise]; the horizontal sundial (*al-rukhāma*); the conical sundial (*al-mukḥula*); and the board (*lawḥ*)."

Could it be that with this last reference al-Khwārizmī was referring to a board from which one could reckon the time of day accurately for any day of the year and for any latitude? Something like the Regiomontanus dial (see **10**)? Why does the 18th-century illustration in the Cairo manuscript use the value of the obliquity first derived by Ḥabash and popular in the Islamic East only until the 12th century, after which it was used sparingly until the 15th? Or something like the Brechte plate (**13**)? As I have already noted, all of the components on that plate—except, perhaps, the universal horary dial—were known in 9th- or 10th-century Baghdad. This would be a companion instrument to the very early device known in various medieval Arabic sources as *al-mīzān al-Fazārī*, which means something like "multiple-scale-ruler of al-Fazārī", the latter appparently to be identified with the well-known 8th-century Muslim astronomer of this name. This ingenious device consists of a series of scales, some numerical, some graphical.[2] It was known, for example, in 13th- and 14th-century Egypt, but apparently unknown in medieval Europe. On the other hand, the rectangular vertical sundial with a gnomon movable on a horizontal solar longitude scale, called in Arabic *sāq al-jarāda*, "locust's leg", is another early Islamic instrument: maybe al-Khwārizmī was referring to this when he mentioned the *lawḥ*?[3]

Another point: the Latin *navicula* text[4] ends with a discussion of the use of the *navicula* for timekeeping by the stars which is frankly absurd unless one is dealing with stars with declination less than the obliquity (which is apparently not stated in the text). If one had a scale for declinations up to, say, about 45° instead of, or in addition to, a solar scale, it would not be absurd.[5] But there is no space on the *navicula* for such a stellar declination scale. See **Fig. 10f** for Apian's solution to this problem.

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[1] Abū ʿAbdallāh al-Khwārizmī, *Mafātīḥ al-ʿulūm*, p. 232 (pp. 125-126 of the pirate edition, Cairo, 1342 H [= 1942]. See already King, *Mecca-Centred World-Maps*, p. 353, n. 102.

[2] See, for example, the discussion of al-Marrākushī (Cairo, *ca*. 1280) recorded in Sédillot-*père*, *Traité*, pp. 458-473 and figs. 80-84; Sédillot-*fils*, "Mémoire", pp. 46-54; and also Charette, *Mamluk Instrumentation*, II-6.2. On al-Fazārī see the article "al-Fazārī" by David Pingree in *DSB*. The provisional association of this device with an 8th-century astronomer needs further investigation. Certainly the instrument described by al-Marrākushī is a later version of a hypothetical early original device. For another source on this important instrument, as yet unstudied, see *Cairo ENL Survey*, no. C24 (4.7.4).

[3] This possibility is suggested in Charette, *Mamluk Instrumentation*, II-4.1. For an example of such an instrument see

#7315—vertical sundial for Damascus and Aleppo by Abu 'l-Faraj ʿĪsā dated 554 H [= 1159/60]—Paris, Bibliothèque Nationale de France, inv. F. 6909—(7315) see Casanova, "Cadran solaire syrien"; and *Paris IMA 1993/94 Exhibition Catalogue*, pp. 436-437 (no. 332), also **Fig. IV-7.4** and **XIVb-1**.

[4] The Middle English text breaks off before this point.

[5] See n. 10:11.

Previously I have wondered whether anyone would have made a complex instrument for timekeeping by night if they had not already made a simpler one for timekeeping by the sun? Now I would prefer to ask, if one had experimented with this kind of instrument for the stars, would it not be a good idea to seek to a simpler instrument using only the declination of the stars, rather than all of their coordinates? In other words, it is not certain that this instrument of Ḥabash did not precede the universal horary dial such as we find on the *navicula* or on the Brechte plate.

It seems to me useful to look again at the universal horary dial on the *navicula*, for which we do not have an original Arabic text, in the light of Ḥabash's instrument, for which we do have such a text. The former consists of the following features:

(1) A linear latitude scale based on tan ϕ, as on Ḥabash's instrument.
(2) A movable cursor within that scale. On Ḥabash's instrument a cursor moves on a different linear scale.
(3) Two scales displaying $\delta(\lambda)$ within an arc of length 2ε, as on the 9th-century "*quadrans vetus*". Ḥabash's instrument has the declination scale over an entire quadrant of arc. On the *navicula* the side declination scale is ingeniously adapted to give tan $\delta(\lambda)$ rather than $\delta(\lambda)$.
(4) A double set of parallel markings for the (co)sine function, as opposed to the three single sets on Ḥabash's instrument.
(5) An ingenious mechanical device for inserting both $\mathcal{E}$ = tan δ tan ϕ and $\mathcal{G}$ = sec δ sec ϕ. On Ḥabash's instrument there is a mechanical device for inserting max $\mathcal{E}$ = tan ε tan ϕ so as to find the oblique ascensions for any ϕ and λ.

I strongly suspect that Ḥabash was the first to devise such markings, not just because he was very clever,[6] although he certainly was, but because he invented a yet more complex instrument for timekeeping by the stars, which has similar principal components. But his hypothetical dial may have served the stars as well as the sun, that is, its declination scale may have gone beyond the obliquity of the ecliptic. This feature it would have had in common with his other device. And, of course, there is no reason to suppose that the hypothetical instrument was shaped like a ship.

Neither the hypothetical universal horary dial of Ḥabash, nor apparently his dial for the stars, had much success in the Islamic world. One major disadvantage of the sinical markings on the hour dial such as we find on the *navicula* was that the markings beyond the 10th hour on either side are uncomfortably crowded. Some Muslim astronomers obviously favoured a mathematical device in which this was avoided: see **16**.

Now how might this hypothetical Islamic universal horary dial have been transmitted to England? Here we are not at all on firm ground, but we can take advantage of the new insights into transmission gained as a result of some recent discoveries by colleagues. Alas for my argument, there is not a trace of the universal horary dial in the rather-well-documented

[6] *Contra* North, "Review", col. 749, cited at the beginning of this paper.

literature on astronomical instrumentation from medieval Syria and Egypt.[7] So I am tempted to dismiss the possibility of, say, some Crusader picking up the idea in that part of the world. It would also be remarkable if some Englishman had picked up the idea in Venice, although that would at least help to account for the name of the device in its English manifestation. Another theoretical possibility would be Sicily, where, for example, the design of Maghribī astrolabes from *ca*. 1200 seems to have inspired one branch of Italian instrumentation,[8] and the Jewish astronomer Isaac al-Hadib, a refugee from al-Andalus who arrived at the end of the 14th century, wrote on instruments that are not fully in the known Islamic tradition.[9] But about the transmission of astronomical knowledge to, from or through Sicily we simply know too little.[10] This leaves al-Andalus, the name given to that part of the Iberian Peninsular under Muslim domination at any given time. But there is no trace of the device there either.[11] However, what we know about science in al-Andalus is very much a question of chance since most of the original manuscripts and instruments are lost, and the fortuitous rediscovery of a single instrument or text from that milieu can turn upside down prevailing opinions. I refer, for example, to the rediscovery of a Latin astrolabe from 10th-century Catalonia in the 1950s;[12] a recension of the 13th-century astronomical handbook of the Tunisian astronomer Ibn Isḥāq, the most important work of its kind in the Maghrib, full of new material from otherwise lost Andalusī sources, in the 1970s;[13] a sophisticated mathematical treatise by Ibn Hūd, king of Saragossa, in the 1980s;[14] and of an astrolabe from 14th-century Toledo with inscriptions in Hebrew, Latin and Arabic, in the 1990s.[15] Thus it is perfectly possible that such a hypothetical Arabic text on the universal horary dial, if such existed, might have been available at some time in al-Andalus, although certainly it did not end up in the 13th-century *Libros del saber de astronomía* associated with King Alfonso el Sabio. But nor did the *sexagenarium*—a sine quadrant with a uniformly-spaced sexagesimal orthogonal grid, a variant of which with sinically-spaced sexagesimal markings was known already in 10th-century Baghdad, although it too did end up too in England in the 14th century.[16]

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[7] See King, "Astronomy of the Mamluks", and, more specifically, Sédillot-*père*, *Traité*, and Sédillot-*fils*, *Mémoire*, and Charette, *Mamluk Instrumentation*.

[8] King, "Urbino Astrolabe", pp. 110-111 and 118.

[9] Goldstein, "Astronomical Instruments in Hebrew".

[10] The only known astronomical handbooks with tables (*zīj*es) serving Sicily appear to be in Hebrew: see King & Samsó (with Goldstein), "Islamic Astronomical Handbooks and Tables", p. 67 and also pp. 60-61. On a value of the obliquity of the ecliptic attributed to King William II (Ghiyām ibn Rujjār) of Sicily reported by the 13th-century Tunisian astronomer Ibn Isḥāq see now Mestres, Zīj *of Ibn Isḥāq*, p. 4.

[11] See *Madrid MAN 1992 Exhibition Catalogue*, and the numerous other recent works of the Barcelona School.

[12] See n. 1:5, and especially Destombes, "Carolingian Astrolabe", and the various studies collected in Stevens *et al*., eds., *The Oldest Latin Astrolabe*, also **XIIIa-9**.

[13] See King, "Maghribī Astronomy", p. 32; Samsó, "Maghribī *Zīj*es", p. 93; Mestres, "Hyderabad MS of the *Zīj* of Ibn Isḥāq", and the detailed study in *idem*, Zīj *of Ibn Isḥāq*.

[14] See Hogendijk, "Al-Mu'taman ibn Hūd".

[15] See the detailed description in King, "Toledo Astrolabe".

[16] On the 10th-century source see **Figs. X-6.1.1-2**. The English instrument is:

#5550—Oxford, Museum of History of Science, inv. no. ?—see Gunther, *Early Science in Oxford*, II, pp. 173-174 (no. 69) and the plate before p. 175; also Poulle, "*Instruments astronomiques*", 1983 edn., pp. 38-39; and especially *idem*, "Sexagenarium", and now Aguiar & Marrero, *Sexagenarium*.

There are two other possible ways of transmission of medieval Islamic astronomical knowledge to England. One is through the medium of a certain Christian Arab named "ʿAbd al-Masīḥ of Winchester", about whom little is known except that he was involved in interpretations of the Latin *Almagest* in the second quarter of the 12th century.[17] The other, also in the 12th century, involved reworkings of 10th-century Islamic tables for Shiraz to the meridians of Pisa and London, some at the hand of Ibn Ezra on a visit to Pisa.[18] All of this activity seems a little early to have been the scene for the introduction of the *navicula* in England.

It is extremely unlikely that the association of our instrument with a Venetian ship is from al-ʿIrāq. But it could come from Syria or Egypt.[19] Yet it is more probably a purely European appelation and still cries out for an explanation (see **6e**).

One last thought: suppose there was an Arabic text with the word *māʾil*, pronounced in Middle Arabic *māyil*, for a rotatable rule that should be inclined (Arabic *māla*, active participle *māʾil*) to show the declination, and this was not fully understood by a hypothetical translator who thought the word sounded rather like *māl-us*, "mast of a ship". But, alas, Ḥabash does not use the term *māʾil* in his treatise on the universal instrument for timekeeping by the stars. And we are again on dangerous ground.

15 The German tradition of the "other" *organum Ptolemaei*

There is another instrument, unrelated to the universal horary dial in form and conception if not in purpose: I refer to the analogue computer device also known by the name *organum Ptolemei*. The *instrument* is unknown from Antiquity and from the Islamic world, but in the earliest Latin texts, dating from the 15th-century and associated with Peuerbach and Regiomontanus, it is attributed to Ptolemy.[1] The *orthogonal projection of the celestial sphere which underlies this instrument* was, of course, known in Antiquity and in the Islamic world, and

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[17] Burnett, "ʿAbd al-Masīḥ of Winchester". On the indebtedness of contemporaneous mathematical astronomy in Europe to Islamic sources see also Mercier, "Astronomical Tables in the 12th Century".

[18] *Ibid*., pp. 108-112. On the Pisa-Antioch connection see Burnett, "Antioch as a Link between Arabic and Latin Culture".

[19] The Arabic historical sources are generally silent on the nature of the ships used by the Muslims, let alone their trading-partners or adversaries (see the article "Baḥriyya, I. The navy of the Arabs up to 1250" by A. S. Ehrenkreutz in EI_2, supp.). Considerable information is available in medieval miniatures, some of which have been collected by an art historian, albeit in a rather haphazard fashion: see Suʿād Māhir, *al-Baḥriyya fī Miṣr al-islāmiyya wa-āthāruhā al-bāqiya* [= *The Navy in Islamic Egypt and the Surviving Evidence*], Cairo: Dār al-kātib al-ʿarabī li-'l-ṭibāʿa wa-'l-nashr, n.d. [*ca*. 1968]. Surprisingly there is no article on Venice (*Bunduqiyya*) in the EI_2 dealing with the city in the Middle Ages as seen from the Muslim world.

[1] Until recently the best discussion was in Zinner, *Astronomische Instrumente*, pp. 131-134, which I refrain from summarizing. John North has sorted out some of the confusion regarding the available texts: see his "Meteoroscope", p. 58, n. 7.

As Zinner was aware, the *organum* goes back at least to Regiomontanus, and the underlying mathematics was known already to Ptolemy (hence the medieval name). A valuable new study is in Zenner, "Analemma".

A more recent study, Dupré, "Instruments and Orthographic Projection", boldly states (p. 10) that:

> " ... the concept of an orthographic projection ... ... was only acquired during the 16th century in the circles of mathematicians interested in mathematical instrument design."

eventually also in medieval Europe (**Fig. VIII-3.3**).[2] It is related to the construction known since Antiquity as the *analemma*, by which the basic formulae of spherical astronomy can be derived by plane rather than spherical trigonometry: see **I-1.2**.

The instrument consists essentially of a circular plate bearing firstly a set of ellipse segments representing the orthogonal projections of the meridians for each equinoctial hour or fractions thereof, and secondly a family of parallels to the celestial equator for the declinations. Sometimes, the declination lines serve only the sun and there is a declination scale on the circumference. Above these markings can rotate either (1) an alidade to represent the local horizon and fitted with a movable perpendicular attachment marked with a non-uniform scale, or (2) a semi-circular grid bearing a diameter for the horizon and a set of parallels representing celestial altitudes, or (3) some modification of these.

The first attested use of the *organum Ptolemaei* on an instrument is, appropriately, on two out of close to a dozen astrolabes of the "Regiomontanus-type": firstly, one dated 1462 which Regiomontanus presented to his patron Cardinal Bessarion,[3] and another, which may actually be earlier (it has inscriptions in Gothic script rather than Italica), but which bears a later inscription by an owner dated 1535.[4] On both pieces the *organum* is engraved on a movable plate which fits onto or rather into the back; on the former the other side of the plate is without engraving, and on the latter the other side bears a universal horary quadrant and an horary quadrant for latitude *ca*. 48° as well as a double shadow square. See **Fig. 15a**.

Gerard Turner has (independently of his former co-author) claimed that the *organum* was an "alternative" to the universal horary quadrant.[5] I would argue that the universal horary dial is the counterpart of the universal horary quadrant, for both are "mathematical" devices. The *organum* is an analogue device of more "astronomical" nature, and as such is the counterpart of the universal astrolabic plate, which was also occasionally added to the standard astrolabe.[6]

Another *organum* is found on an astrolabic plate attached to a celestial globe made in 1480

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[2] Of interest here is a unique 11th(?)-century dial marked with an orthogonal projection including the celestial equator, tropics, polar circles, and an unlabelled horizon for the latitude of the 7th climate (*ca*. 48°). See:

#8500—Regensburg, Stadtsmuseum—see Zinner, "Lehrgerät", and **VIII-3** (illustrated), corresponding to King, "Aspekte", p. 140-141. For a more detailed study of this piece see Wiesenbach, "Astrolab und Astronomie im 11. Jahrhundert", pp. 135-142, which was kindly brought to my attention by Friederike von Morr (Frankfurt).

[3] #640—private collection—see Price, "Regiomontanus' Astrolabe"; and King & Turner, "Regiomontanus' Astrolabe", pp. 170-186 and figs. 1-9.

[4] #256—present location unknown. See Gunther, *Astrolabes*, II, pp. 434 (no. 256); King & Turner, *op. cit*., p. 189 and figs. 18-19; and the more detailed description by Gerard L'E. Turner in *Christie's London 08.04.1998 Catalogue*, pp. 70-73 (lot 49).

[5] G. Turner, *ibid*., p. 73:

> "The *organum Ptolemei* was developed as a device for accurately reckoning time from solar altitude in equinoctial hours. It was an alternative to the universal horary quadrant popular on astrolabes both before and after the fifteenth century. This was an inferior device for reckoning time from solar altitude, giving approximate values in planetary hours. Both devices were popular because they worked for all latitudes, but the quadrant was easier to construct and was far more widely used."

[6] See n. 3:2.

by the Benedictine monk Hans Dorn, who was a product of the Vienna school.[7] Yet another is found inside his splendid astrolabe made in 1483: see **Fig. 15b**.[8] An unusual South German instrument preserved in Munich datable *ca*. 1550 and signed "AI" bears an *organum* on one side (**Fig. 15c**) and a calendrical / solar scale and shadow square on the other. The alidade for the front bears a line parallel to diameter for twilight operations, and a perpendicular radius.[9]

An *organum* is illustrated in the 1574 *Cosmographia* of Peter Apian (**Fig. 15d**).[10] It also features in the 1538 and 1558 Wittenberg editions of Sacrobosco's *De Sphaera* (**Fig. 15e**).[11] The projection associated with de Rojas (Paris, *ca*. 1550)[12] is apparently derived directly from the German tradition: **Fig. 15f** shows a 16th-century astrolabe from Florence bearing this projection on the back.[13] Two later Islamic instruments, both from Safavid Iran, bear the same kind of markings, apparently under European influence: for one of these, see **Fig. 15g**.[14/15] All of these sources and the other relevant materials should perhaps be investigated afresh.

One feature and drawback that the universal horary dial and the *organum* have in common is that the markings at the sides are uncomfortably crowded together. This is one reason why the universal plate with its stereographic projection and comfortably spaced markings was more widespread. But it was not the only solution to that problem.

16 The orthogonal projection in the Islamic sources

To the question whether the *organum* too was known in the early Islamic world, I can only answer that it is not mentioned in any known Islamic textual sources. However, certainly the underlying astronomy and mathematics was known to every serious Muslim astronomer from the 9th to the 19th century. A similar but different mathematical combination of markings was used by certain Muslim astronomers.[1] The mapping, projection, mathematical device, call it what one may, has two advantages over that of the *organum*: first, the meridians are equally-

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[7] #4510—Cracow, Jagiellonian Museum, inv. no. 4039-37/V—see King, "Astronomical Instruments beteween East and West", p. 188, with references to Polish publications; and *Washington 1992 Exhibition Catalogue*, pp. 221-222 (no 120).

[8] #492—Florence, Museo di Storia della Scienza, inv. no. 1096—see King, "Astronomical Instruments beteween East and West", p. 186; also EPACT.

[9] #8512—Munich, Deutsches Museum, inv. no. 1696—see *Munich Catalogue*, pp. 243-251 (no. 8).

[10] This instrument is not mentioned in Röttel, ed., *Peter Apian*.

[11] See also Gingerich, "Sacrobosco Illustrated", pp. 215-216, and fig. 6 on p. 222, and *idem*, "Paper Instruments with Moving Parts", p. 67.

[12] See Maddison, "De Rojas Projection".

[13] #4580—Liège, Musée de la Vie Wallonne, inv. no. 36—see *Brussels 1984 Exhibition Catalogue*, pp. 41-42 (no. 12).

[14] #1207—Observatoire de Paris—see King, *Mecca-Centred World-Maps*, p. 320.

[15] #3670—St. Petersburg, Hermitage Museum, inv. no. VC 512—illustrated in Maistrov, *Nauchnye pribory*, p. 43 (no. 17) and pls. 81-82; also *Mecca-Centred World-Maps*, pp. 321-322 and n. 134.

[1] For references to the materials mentioned in this paragraph see Kennedy & Debarnot, "Two Mappings of al-Bīrūnī"; Puig, "La proyección ortográfica en el Libro de la açafeha", "Proyección ortográfica", and "Ibn al-Zarqālluh's Orthographic Projection"; King, *Mecca-Centred World-Maps*, p. 36, nn. 68-69, and pp. 342-343, nn. 57-58.
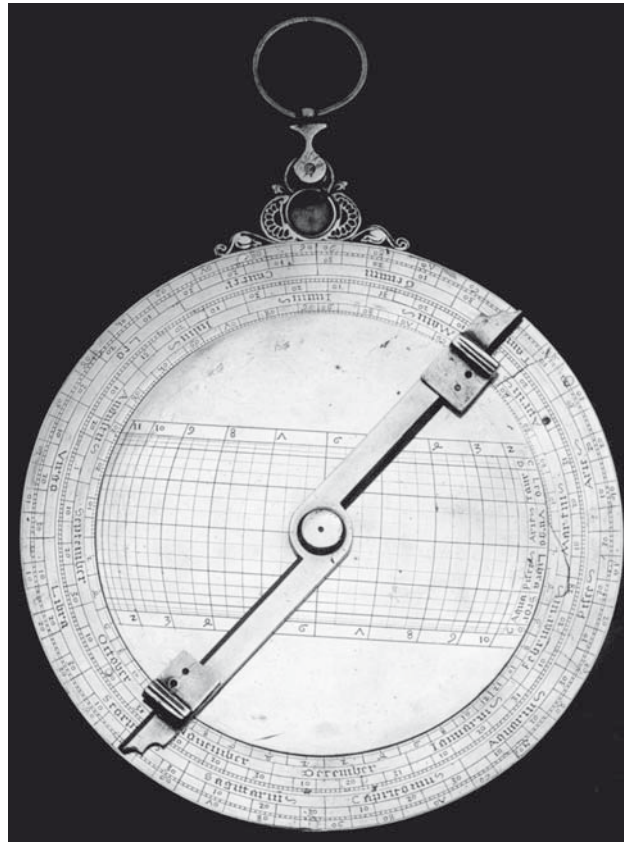
Fig. 15a: The rotatable *organum* on the back of an astrolabe (#256) from the same workshop as the piece presented by Regiomontanus to Bessarion in 1462 (#640). This piece is not dated, neither is it signed. [Private collection, photo courtesy of Christie's of London.]
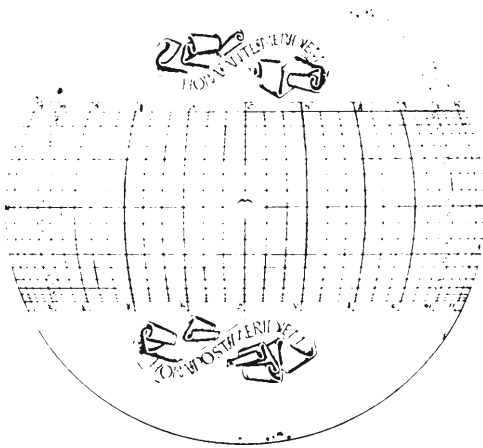
Fig. 15b: The *organum* inside Hans Dorn's 1480 astrolabe (#492). [Courtesy of the Museo di Storia della Scienza, Florence.]

Fig. 15c: An unusual *organum* from 16th-century Southern Germany (#8512) with a diametral rule bearing a bar parallel to the horizon for determining twilight. [Courtesy of the Deutsches Museum, Munich.]
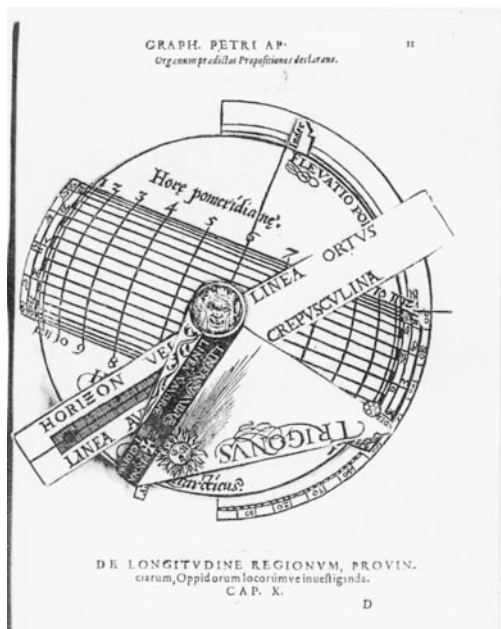
Fig. 15d: Apian’s *organum* with a ruler to be used for both movable horizon and line of solar depression at twilight, as well as a trigon and a radial rule for shadows (??). Note the little *wilder Mann* decorating the central knob. [From Apian, *Cosmographia*, 1574 edn., p. 11. See also Zinner, *Astronomische Instrumente*, p. 133.]
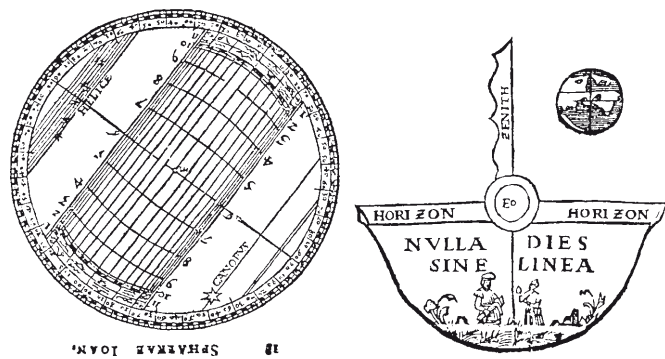
Fig. 15e: An *organum* with a movable part shaped like a real *navicula* in an unidentified edition of Sacrobosco’s *Sphaera*. [From Zenner, “Analemma”, fig. 7.]
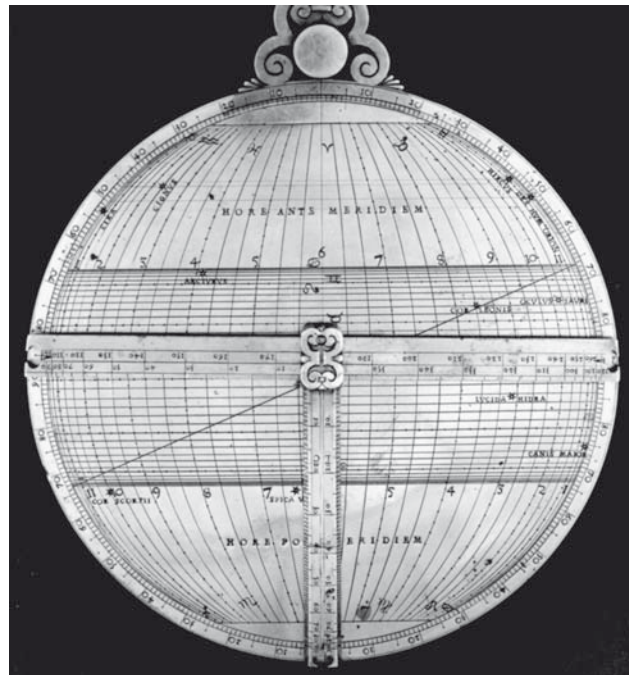
Fig. 15f: The so-called “de Rojas” projection with alidade and movable cursor on the back of a 16th-century Italian astrolabe (#4580). [Courtesy of the Musée de la Vie Wallonne, Liège.]

spaced and do not crowd together; and second, the meridians are arcs of circles not segments of ellipses. I refer to the “mapping” known in the history of cartography as “globular”. This is found in the Islamic world in:

(1) the treatise on cartographic mappings by al-Bīrūnī, compiled in Central Asia in the early 11th century;

(2) on universal astrolabic instruments invented in al-Andalus in the late 11th century (see **Fig. XI-8.3a**) and popular for centuries thereafter (**Fig. 16a**[2]); and

[2] #102—London, Victoria and Albert Museum London, inv. no. 31—unpublished; see Gunther, *Islamic Astrolabes*, I, p. 233 (no. 102); and Mayer, *Islamic Astrolabists*, p. 31.
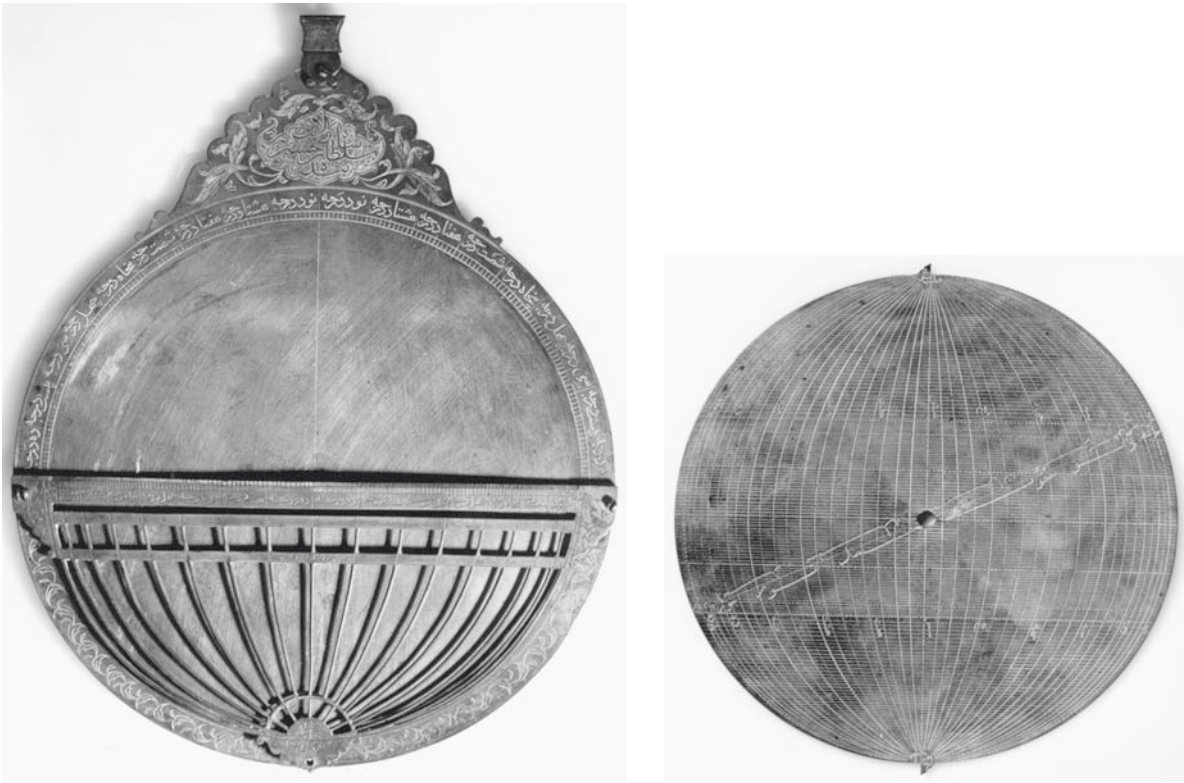
Fig. 15g: The rete and plate of a remarkable astrolabe dedicated to the Safavid Shāh Ḥusayn *ca*. 1710 (#3670). The meridians on the plate are labelled for the hours, and the horizon on the semi-circular rete is ready to go. However, as on most European instruments, it is not clear to me how one should enter the altitude above the horizon, unless with a loose ruler held parallel to the horizon. Also, it looks as though the rete is fixed to the limbus, and the plate cannot be rotated beneath it. An instrument that can only be used at the equator? [Courtesy of the Oriental Department of the Hermitage Museum, St. Petersburg.]

(3) on a world-map copied in Egypt in the 14th century, if not before.

It is not unreasonable to suspect an earlier common source predating al-Bīrūnī. The same projection appears in 13th-century England with Roger Bacon. This mathematical device was certainly not widely known amongst Muslim astronomers.

17 Concluding remarks

Now there are about 10,000 surviving manuscripts in Arabic (also Persian and Turkish) dealing with astronomy, most of which were copied after, say, 1550. Most of the manuscripts copied before then have not survived the vicissitudes of time. What we know about *early* Islamic astronomy is very much a matter of chance, for it has, in the main, to be reconstructed from materials in later works or in later manuscripts. Some aspects of late Islamic science can be understood only when their inspiration is found in early Islamic texts. Some aspects of medieval European astronomy, on the other hand—and here I am thinking particularly of the universal
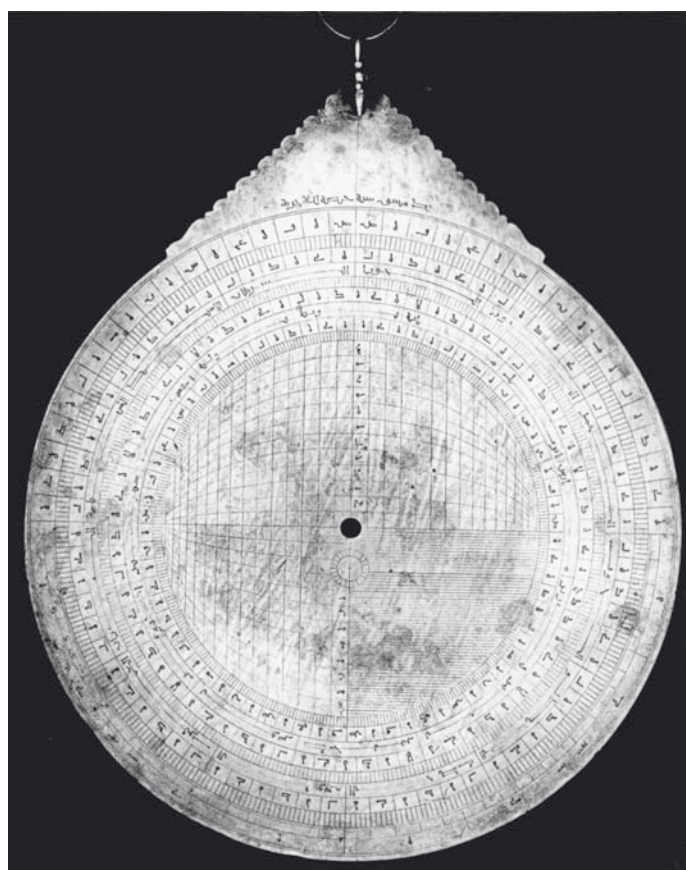
Fig. 16a: The orthogonal projection on the back of a universal astrolabic plate (*zarqālliyya*) made by ʿAbd al-Raḥmān ibn Yūsuf in Damascus in 695 H [= 1295/96] (#102). The little "circle of the moon", also invented by the 11th-century Andalusī astronomer Ibn al-Zarqālluh, is visible just below the centre: as Roser Puig has shown ("Al-Zarqālluh's Graphical Method", 1989), this is a highly ingenious device for determining lunar distance and parallax. Note that the calendrical scale is for the *Western* calendar as used in al-Andalus, rather than any of the calendars used in the Eastern Islamic world. Yet the astrolabic plate of al-Wadāʿī (see **Fig. XIVc-3.1**), with scales for both the Coptic and Syrian calendars, dates from the mid 13th century. [Courtesy of the Victoria and Albert Museum, London.]

horary quadrant and shadow square—, can only be fully appreciated from early Islamic treatises which just happen to be preserved only in late manuscripts.

The best examples of reconstruction from later works are surely David Pingree's writings on the early astronomers al-Fazārī, Yaʿqūb ibn Ṭāriq and Abū Maʿshar.[1] But also some fine detective work has been done by other researchers, such as Jan Hogendijk, who reconstructed al-Khwārizmī's lost sine table from values in a mysterious table for timekeeping.[2] Here are some examples relating to instruments from manuscripts copied centuries after the works they contain were first compiled:

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[1] Pingree, "al-Fazārī", "Yaʿqūb ibn Ṭāriq", and *The Thousands of Abū Maʿshar*.
[2] See **I-4.3.1** and **XI-9.3**.

Fig. 17a: *Zawraqī* markings for eight different latitudes on a "rete" that can be rotated over a "plate" bearing a set of astrolabic markings for the ecliptic and fixed stars, as illustrated in al-Bīrūnī's treatise on astrolabe construction, *al-Istīʿāb*. Each side of the four prongs, which are incorrectly shown as concentric arcs of circles, bears a half horizon for a specific latitude. The name *zawraqī*, "shaped like a ship", was clearly derived from a pair of single but complete horizons bounding a crescent-shaped band: see **Fig. 17b**. [From MS Istanbul Carullah 1451, fol. 29v, courtesy of the Süleymaniye Library.]

Fig. 17b: This diagam in al-Marrākushī's treatise illustrates how the name *zawraqī* came into al-Sijzī's mind. Two latitudes are specified here, one on the upper side of the "hull" and the other on the lower side. [From MS Paris BNF ar. 2508, fol. 49v, courtesy of the Bibliothèque Nationale de France.]

- al-Khwārizmī's treatise on the construction and use of the astrolabe survives in a unique manuscript in Berlin copied *ca*. 1500.[3]
- The treatise on Ḥabash's computing device for timekeeping by the stars survives in a unique manuscript in Oxford copied in 1242.
- The anonymous 9th-century Baghdad treatise on the universal horary quadrant with movable cursor survives in a unique manuscript in Cairo copied in Meshed *ca*. 1800.
- The only known illustration of a universal horary dial in the Islamic sources is to be found in a manuscript copied in Istanbul *ca*. 1740.

We may also mention some late Islamic instruments on which other early innovations are represented:

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[3] The treatise on the use of the astrolabe was published in German translation by Joseph Frank in 1922. On the other treatise see King, "al-Khwārizmī", pp. 22-27. Both are now edited with English translation and commentary in Charette & Schmidl, "al-Khwārizmī on Instruments".

- The *zawraqī* horizons on astrolabe retes, first described in a (non-extant) book by al-Sijzī (*ca*. 990) and briefly mentioned in his book on instrument construction, which are otherwise known only from later texts, such as those of al-Bīrūnī and al-Marrākushī, and on astrolabes from Lahore and Delhi in the 16th and 17th centuries.[4]
- The grids on Mecca-centred world-maps for finding without any calculation the direction and (sine of) the distance to Mecca, known only from three 17th-century examples which are clearly copies of an earlier prototype. I have shown that the geographical data on the maps is taken from a 15th-century source, and that the formula relating the direction and the sine of the distance that underlies the grid was derived by Ḥabash in the 9th century. Jan Hogendijk has established that the determination of the qibla by conic sections (the circular arcs on the grids are approximations to ellipses) is discussed in a treatise from 10th-century Baghdad by Abū Jaʿfar al-Khāzin, an author midway between Ḥabash and al-Bīrūnī, and in another from mid-11th-century Isfahan by a lesser-known author, Abū ʿAbdallāh Muḥammad ibn Aḥmad al-Khāzimī, who elsewhere cites al-Bīrūnī.[5]

And there are examples of innovations of which we have no later Islamic examples, such as:

- The scales on the instrument called *al-mīzān al-Fazārī*.[6]
- The transversal scales described by al-Sijzī, mentioned above, otherwise first attested in the writings of Levi ben Gerson *ca*. 1320.[7]

I would be the first to admit that I have failed in my attempt to locate an early Arabic text on the universal horary dial. But it would not surprise me if, one day, in some manuscript library in Turkey or Iran, or even in Oxford or Paris, a manuscript is discovered containing a short text from 9th- or 10th-century Baghdad describing an instrument essentially—at least from a mathematical point of view—identical with the universal horary dial such as we find, in one manifestation, on the *navicula*, and, in another, on the Brechte plate.

To summarize my conclusions:

- I have identified two different traditions in the medieval English *navicula*s. One is attested by the published texts and the instruments associated with Oxford, Florence, Greenwich and Colchester. The other is attested by the instrument now in Geneva.
- I have shown that all of the components of the universal horary dial on the front of at least the Geneva *navicula*—a latitude scale based on tan ϕ, a declination scale for $\delta(\lambda)$, and the sinical horary markings—were, like the universal horary quadrant and the shadow scale on the back of the *navicula*, known in 9th-century Baghdad. I have also shown that an instrument for timekeeping by the stars for all latitudes was devised by Ḥabash al-Ḥāsib in that environment. Both instruments use a mechanical device to achieve their aims, which are to generate standard auxiliary functions of Islamic timekeeping.

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[4] See n. 1:7.

[5] See King, *Mecca-Centred World-Maps*, pp. 195-371, on the first two, and **VIIc** on the third and Hogendijk's findings. On the choice of data see n. 9:13 above.

[6] See n. 14:2, and also **XI-6.4** and **7.2**.

[7] Goldstein, *The Astronomy of Levi ben Gerson*, p. 149.

- I have shown that the universal horary dial existed in more than one form already before 1450: the English *navicula*s of the 14th century, and the German circular plate of 1434.
- I have found an early-16th-century instrument with a third form, which is more "original" than the other two, in that it is not shaped like a ship, and is not of the German varieties preceding the *Uhrtäfelchen* of Regiomontanus. Alas the instrument is not correctly assembled to achieve an exact solution.

To summarize the problems that I have not been able to solve in this study:

- Who was it who first had the brilliant idea of combining a non-uniform latitude scale based on tan ϕ, which also defined sec ϕ, and a non-uniform declination scale based on tan δ, which also defined sec δ, and further conceiving a mechanical device to generate the quantities $\mathcal{E}$ = tan ϕ tan δ and $\mathcal{G}$ = sec ϕ sec δ and hence yield a solution to the problem of finding $t(h,\delta,\phi)$ on a set of non-uniformly spaced horary markings? Alas I still do not know.
- The *navicula* appears out of the blue in 14th-century England. Two of its three main components came from 9th-century Baghdad. Where did its third and most sophisticated component, the universal horary dial, come from? Why were there two traditions?
- Why did the person, presumably an Englishman, who decorated the markings in the form of a ship associate that ship with the Venetians?
- An earlier, less developed, version of the same device, not in the form of a ship, is found in Vienna in the 15th century. Where did it come from? Perhaps from England? Like the albion of Richard of Wallingford, of which the sole surviving example is from Vienna? There were people who could have devised a universal horary dial in 15th-century Vienna, but their leading representative, Regiomontanus, said he took it from older sources, which he alas did not identify.
- What were the medieval universal dials known to Regiomontanus? Clearly he knew of the kind illustrated in **Fig. 10a** (and **Fig. 2c-d**) because that comes from his milieu. But did he know the kind found on the Brechte plate or on the English *navicula*s? Was the contribution of Regiomontanus to this whole business nothing more substantial than to propose a latitude "scale" composed of horizontal parallels in order to avoid the "fine tuning" I have proposed when setting the bead on the thread on an instrument of the Geneva type?[8]
- Is the Florence *navicula* really English? If so, why does it so closely resemble in principle the circular dials of the 1434 German tradition and differ so significantly from the three "new" English *navicula*s? Could it be German? Somehow I doubt it, and I have given my reasons.

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[8] John North (*Richard of Wallingford*, II, pp. 29-31) has already pointed out that Regiomontanus' contribution to trigonometry was less than has been claimed in von Braunmühl, *Geschichte der Trigonometrie* (1900). In fairness to Regiomontanus, though, North did not mention Regiomontanus' tables for solving spherical triangles (see **I-10.2**). For some exciting new research on the mathematical astronomy of the Vienna school see Kremer & Dobrzycki, "Peurbach and Marāgha Astronomy?". It is always healthy to look again at the original sources some decades after others have "exhausted" them: on this theme see King, *Ciphers of the Monks*, p. 2, n. 2.

- ❖ What was the environment of Brechte in England, where alone some of the saints featured on its calendrical dial were venerated? And what inspired the German (?) Brechte with the Anglo-French (?) first name Roger to construct an instrument featuring mainly state-of-the-art astronomical features from 9th- and 10th-century Baghdad, most of which are not attested on any other known European instrument from the Middle Ages, and in some cases, also the Renaissance?

The history of universal horary dials from its beginnings to the late Renaissance calls out for a detailed investigation. In this study I hope to have provided the initial stimulus for such an endeavour. Any accepted conclusions or over-enthusiastic hypotheses could be blown away by "the slightest breath of new evidence".[9] In brief we are talking about a future doctoral dissertation for someone who can handle first the trigonometry of spherical astronomy and second the primary sources in medieval Arabic, medieval Latin, Middle English and Middle German, as well as secondary sources in English, German and Italian. He or she will have to work on the previously-unstudied documents from both the English and German tradition of the universal horary dial.[10] That future researcher also needs to understand the language of instruments, medieval and Renaissance, which is quite different from the language of any texts. Attention should be paid to the texts on the *construction* of the various dials, which I have neglected here, and to the details of the individual instruments. A major contribution would be to explain the motivation behind the mathematics underlying the construction of the "modified" *navicula*. The history of the dial after *ca*. 1550 should also be investigated afresh.[11] The same person will also need some good luck to discover some new sources—instruments, texts, diagrams or tables—that are relevant to the topic.[12] But this is not too much to hope for: the three *navicula*s from 14th-century England all came to light only during the past 15 years!

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[9] John North in Burnett, ed., *Adelard of Bath*, p. 160, on a different topic.

[10] On the English manuscripts yet to be studied at all see n. 2:4.

[11] See, for example, the instrument from a shipwreck cited in n. 10:11, and also the text to n. 13:5. But one has to beware of fakes: see the dubious-looking "*navicula*" in an instrument-box in the National Library of Australia (inv. no. NK1278) bearing an inscription "Captain James Cook Anno 1750", illustrated in http://nla.gov.au/nla.pic-an7905959.

Proper descriptions of the *modus operandi* of these horary dials are very rare in the recent literature on instrumentation, let alone in works on the history of trigonometry. Thus, for example, those illustrated in Röttel, ed., *Peter Apian*, pp. 87, 88, 93, and 94, are nowhere explained in the accompanying text, which deals in different chapters with timekeeping, instruments and trigonometry.

[12] For medieval European manuscripts relating to astronomy the place to start is Zinner, *Verzeichnisse*. See also Schaldach, "Zinner-Archiv", and Ackermann, "Zinner Archive". See also n. 10:8.

APPENDIX A: A LIST OF EARLY UNIVERSAL HORARY DIALS AND RELATED TREATISES

Note: On the symbol # see n. 1:4 to the main text.

Universal horary dials:

#8531 *Navicula*, English (not German), 14th century (?), perhaps 15th, length 8.15 cm—Oxford, Museum of the History of Science, inv. no. 54358 (formerly G73)—see Gunther, *Early Science in Oxford*, II, pp. 40-41 (misidentified as German); Zinner, *Astronomische Instrumente*, pp. 111 and 116; Brusa, "Navicelle", p. 55 and figs. 3-4; and now Bennett, "Oxford *Navicula*" on EPACT. n. 1:4; Figs. 2a-b

#8532 *Navicula* without fo'c's'ls at the sides, 14th century, German-type design, possibly English provenance (the latitude served by the fixed solar scale on the universal horary quadrant is 52°), length 9.2 cm—Florence, Museo di storia della scienza, inv. no. 3163— see Brusa, "Navicelle", p. 56 and figs. 7-8; and now A. J. Turner, "Florence *Navicula*" on EPACT. nn. 1:4, 10:2; Figs. 2c-d, 6c, 10

#8533 *Navicula*, ivory, signed by Orontius Finus and dated 1524, and presumably made in Paris (the universal horary quadrant bears a zodiacal scale which serves a latitude of *ca*. 48°-49°), the side declination scale is incorrectly graduated, length 14.9 cm—Milan, Museo Poldi Pezzoli, inv. no. 4277—see Brusa, "Navicelle", p. 55 and figs. 5-6; and Fantoni, *Orologi solari*, pp. 414-415 (front and back). nn. 3:14 and 10:9

#8534 Illustration of a *navicula* in a set of copper-plates for various instruments, by Georg Hartmann of Nuremberg, dated 1527—Weimar, Thüringische Landesbibliothek, cod. fol. max 29, fols. 62v-63v—see Zinner, *Astronomische Instrumente*, p. 111. Fig. 10e

#8535 *Navicula*, signed 'SF' (perhaps for Samuel Foster) and dated 1620, possibly French (*fleur de lis* decoration), length 11.2 cm—Cambridge, Whipple Museum of the History of Science, inv. no. 731—see Brusa, "Navicelle", pp. 56-57 and figs. 9-10; *Cambridge WMHS Catalogue*, no. 293; and Eagleton, "*Navicula*".

#8536 *Navicula*, English, 14th century, length 11.0 cm—Greenwich, National Maritime Museum, inv. no. AST1146—see Kragten, *Navicula* (technical discussion); Daniel, "Greenwich *Navicula*", Lippincott, "*Navicula*" (both brief and non-technical); also Hester Higton in *Greenwich Sundial Catalogue*, pp. 249-250 (no. 246), *eadem*, *Portable Sundials*, pp. 26-30 (problematic). n. 2:8; Figs. 2e-f

#8537 *Navicula*, English, 14th century, length 15.2 cm—Geneva, Musée de l'histoire des sciences, inv. no. 2139—see the description by A. J. Turner in *Sotheby's London 25.02.93 Catalogue*, p. 73 (lot 386: "possibly 18th century"[1]) with colour photos on p. 61; G. Turner, *Navicula*; and Archinard, "Geneva *Navicula*". n. 2:8; Figs. 2g-h, 7a-c, 9a-b

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[1] The reticence of Anthony J. Turner to describe the piece as medieval in the Sotheby's auction catalogue was caused by the remark in the *Gentleman's Magazine* of 1787 that readers should make their own instruments copying the illustration of the Colchester piece (see Delehar, "Illustrations", p. 388, and the caption to **Fig. 2i**). Thus a modest price of £5,000 was suggested. (The Greenwich *navicula* had been purchased a few years previously for £80,000.) Since I was stupid enough to tell Sotheby's that the piece was in fact medieval, it sold for £36,000 to a London dealer. He in turn was smart enough to then sell it to a museum for £125,000.

#8538 Illustration of *navicula*, English, 14th century, size unknown—present location of the instrument unknown, *ca*. 1750 in Colchester, Essex—see Delehar, "Illustrations", pp. 386-388. n. 2:8; Fig. 2i

#8539 *Navicula* (?), signed by "Arsenius" in Cologne in 1581, length *ca*. 17 cm—formerly in the British Museum, destroyed in World War II—see Zinner, *Astronomische Instrumente*, p. 111, and *London BM Catalogue*, p. 77 (no. M4); not mentioned in Van Cleempoel, *Louvain Instruments*. -

The manuscripts of treatises on the use of the *navicula* are:

MS Oxford Bodleian Bodley 68—Latin text from 14th century England—see Gunther, *Early Science in Oxford*, II, pp. 375-379 and 38-39 (see also pp. 40-41). n. 6:11, 9e:14

MS Oxford Bodleian Digby 98—Latin text, English provenance, date?—see Gunther, *Early Science in Oxford*, II, p. 41, also with some illustrations.

MS Cambridge Trinity College O.5.26—Middle English text, late-14th-century English provenance—published in Price, "*Navicula*", pp. 402-407.

On the existence of other manuscripts see North, "Meteoroscope", p. 58, n. 7.

Latin manuscripts with geographical tables:

MS Oxford Bodleian Laud Misc. 674 n. 9:11

MS Oxford Bodleian Bodley 68 (see above) n. 9:14

Universal horary dials not in the form of a ship:

#8501 Astrolabic plate with universal horary dial, signed by Roger Brechte and dated 1527—Oxford, Museum of the History of Science, inventory no. 26323 (formerly St. John's College, Oxford)—see Gunther, *Early Science in Oxford*, II, pp. 135-140 (no. 56), especially the illustrations between pp. 136 and 137; also King, *Mecca-Centred World-Maps*, p. 352, and now Meliconi, "Brechte Plate", on EPACT. **13**, esp. n. 13:1; Figs. 13a-d

#8507 An *albion* from 15th-century Vienna with universal horary markings and a declination scale, but lacking a movable part of some sort—Osservatorio astronomico di Roma—unpublished, see North, *Richard of Wallingford*, III, pl. XXIII; and King, *Mecca-Centred World-Maps*, pp. 318-320 n. 10:16; Fig. 10h

- Illustration of a universal horary dial with Arabic inscriptions from 1740—MS Cairo MR 40—*Cairo ENL Catalogue*, I, pp. 439-446, and King, *Mecca-Centred World-Maps*, pp . 352-353 and 355. n. 11:1, Fig. 11a

For manuscripts of the German treatises see Zinner, *Astronomische Instrumente*, pp. 111-113.

Regiomontanus-type dials:

#5524 = #8513 Dial attributable to Hans Dorn *ca*. 1485—Bielefeld, Kunstgewerbesammlung der Stadt, Stiftung Huelsmann, inv. no. HW 97—description in *Bielefeld Catalogue*, pp. 69-70 (no. **9**). n. 10:4, Figs. 10c-d

Organa Ptolemaei:

#256 Astrolabe in the Regiomontanus tradition with later (16th-century) inscriptions—private collection—see Gunther, *Astrolabes*, II, p. 434 (no. 256); King & Turner, "Regio-

montanus' Astrolabe", p. 189 and figs. 18-19; and G. Turner in *Christie's London 08.04.1998 Catalogue*, pp. 70-73 (lot 49). n. 15:4; Fig. 15a

#492 Unsigned astrolabe attributable to Hans Dorn, dated 1483—Florence, Museo di Storia della Scienza, inv. no. 1096—see King, "Astronomical Instruments between East and West", p. 186; and EPACT. n. 15:8; Fig. 15b

#640 Astrolabe presented by Regiomontanus to Cardinal Bessarion in 1462—private collection—see Price, "Regiomontanus' Astrolabe"; and King & Turner, "Regiomontanus' Astrolabe", pp. 170-186 and figs. 1-9. n. 15:3

#4510 Celestial globe with universal dial attached, attributable to Hans Dorn and dated 1480—Cracow, Jagiellonian Museum, inv. no. 4039-37/V—see King, "Astronomical Instruments beteween East and West", p. 188, references to Polish publications; and *Washington 1992 Exhibition Catalogue*, pp. 221-222 (no 120). n. 15:7

#8512 German *organum Ptolemaei* datable *ca*. 1550—Munich, Deutsches Museum, inv. no. 1696—see *Munich Catalogue*, pp. 243-251 (no. 8). n. 15:9; Fig. 15c

For manuscripts on the *organum* from the German milieu see Zinner, *Astronomische Instrumente*, pp. 132-133.

#2 Byzantine astrolabe dated 1062 — Brescia, Museo dell'Età Cristiana, inv. no. 36, on which see Gunther, *Astrolabes*, I, pp. 104-108 (no. 2), after a study by O. M. Dalton (1926); also now **XIIIa-4**. n. 9:5

#100 Astrolabe by Ḥāmid ibn ʿAlī (al-Wāsiṭī), dated 343 H [= 954/55] — present location unknown, stolen from the Museo Nazionale in Palermo — see Mortillaro, "Astrolabio arabo"; King, *Mecca-Centred World-Maps*, p. 356; and now **XIIIc-8.1**. n. 9:2

#102 Astrolabic plate with universal *shakkāziyya*, signed by ʿAbd al-Raḥmān ibn Yūsuf in 695 H [= 1295/96] — London, Victoria and Albert Museum London, inv. no. 31 — unpublished; see Gunther, *Islamic Astrolabes*, I, p. 233 (no. 102); and Mayer, *Islamic Astrolabists*, p. 31. n. 16:2, Fig. 16a

#107 Astrolabic plate with inscriptions in Arabic and Coptic by Ḥasan ibn ʿAlī, dated 681 H [= 1282/83] — Oxford, Museum of the History of Science, inv. no. LE 2019 (new 49861) — see Gunther, *Astrolabes*, I, pp. 239-240 (no. 107); Mayer, *Islamic Astrolabists*, p. 46; and now **XIIIc-3.2**. n. 9:6, Fig. 16a

#290 English astrolabe datable *ca*. 1300 — London, British Museum, inv. no. MLA SL54 — see Gunther, *Astrolabes*, II, pp. 463-465 and pls. CXXVI-VII (no. 290); King, *Ciphers of the Monks*, pp. 383 and 389 (on the quatrefoil decoration); and now Ackermann, "Sloane Astrolabe", on the website EPACT. n. 6:6

#291 English astrolabe dated 1326 — London, British Museum, inv. no. 1909 6-17 1 — see Gunther, *Astrolabes*, II, pp. 465-467 (no. 291); *London BM Catalogue*, pp. 112-113 (no. 325) and pl. LI; also EPACT. n. 1:5

#292 English astrolabe signed by Blakeney and dated 1342 — London, British Museum, inv. no. 53 11-4 1 — see Gunther, *Astrolabes*, II, pp. 468-469 (no. 292); *London BM Catalogue*, pp. 113 (no. 326) and pl. LII; also EPACT. n. 1:5

#298 14th-century English astrolabe — London, British Museum, inv. no. 1914 2-19 1 — see Gunther, *Astrolabes*, II, p. 474 (no. 298), and *London BM Catalogue*, p. 113 (no. 327); also EPACT. n. 9:10

#1130 Undated astrolabe by Nasṭūlus (Baghdad, *ca*. 925) — Cairo, Museum of Islamic Art, inv. no. 15351 — unpublished; see King, "Geography of Astrolabes", pp. 29-31; and now **XIIIc-3.2**. n. 9:6

#1179 10th-century Islamic astrolabe by Muḥammad ibn Shaddād (al-Baladī) with four different shadow-scales on the back — present location unknown, formerly (in 1864) in the collection of Dr. Wetzstein, Berlin — see Dorn, "Drei arabische Instrumente", pp. 115-118 (I, pp. 461-464 of the reprint); King, *Mecca-Centred World-Maps*, p. 354, n. 103; and now **XIIIc-4**. n. 9:4

#1207 Astrolabe signed by Muḥammad Khalīl and Muḥammad Bāqir and dated 1094 H [= 1683], with some unusual plates — Paris, Observatoire de Paris — unpublished; see King, *Mecca-Centred World-Maps*, p. 320. n. 15:14

#2072 Quatrefoil astrolabe owned by Ludolfus de Scicte, treasurer of the Cathedral in Einbeck during 1322-42 — Cracow, Jagiellonian Museum, inv. no. 41/V — unpublished; on the maker see Härtel, "Ludolfus Borchdorp de Brunswik". n. 6:16

#3042 Undated , unsigned astrolabe with Latin inscriptions from 10th-century Catalonia — Paris, Institut du Monde Arabe, inv. no. AI 86-31 — see Destombes, "Astrolabe carolingien"; various papers in Stevens *et al*., eds, *The Oldest Latin Astrolabe*; also King, *Ciphers of the Monks*, p. 440; and now **X-4.8** and **XIIIa-9**. nn. 1:5 and 14:12

#3670 Unsigned 17th-century Iranian astrolabe featuring an orthogonal grid and "rete" — St. Petersburg, Hermitage Museum, inv. no. VC 512 — unpublished; illustrated in Maistrov, *Nauchnye pribory*, p. 43 (no. 17) and pls. 81-82; also King, *Mecca-Centred World-Maps*, pp. 321-322 and n. 134. n. 15:15, Fig. 15g

#4036 Astrolabe with inscriptions in Arabic and Coptic by Ḥasan ibn ʿUmar al-Naqqāsh, dated Cairo, also 681 H [= 1282/83] — Istanbul, Türk ve İslâm Eseleri Müzesi, inv. no. 2970 — unpublished; see King, *Mecca-Centred World-Maps*, pp. 76-78, and now **XIIIc-3.2** and **XV-3.29**. n. 9:6

#4546 14th-century English astrolabe — Innsbruck, Tiroler Landesmuseum Ferdinandeum, inv. no. 2957 — unpublished; see King, "Astronomical Instrumentation between East and West", pp. 168 and 189, and *idem*, *Mecca-Centred World-Maps*, p. 352, n. 94. n. 9:9, Fig. 9c

#4580 16th-century astrolabe with "de Rojas"-projaction on the back — Liège, Musée de la vie Wallonne, inv. no. 36 — see *Brussels 1984 Exhibition Catalogue*, pp. 41-42 (no. 12). Fig. 15f

#5550 14th-century English sexagenarium with calendar scales on the back — Oxford, Museum of History of Science, inv. no. ? — see Gunther, *Early Science in* Oxford, II, pp. 173-174 (no. 69) and the plate before p. 175; also Poulle, "Instruments astronomiques", 1983 edn., pp. 38-39; and especially *idem*, "Sexagenarium", and now Aguiar & Marrero, *Sexagenarium*. n. 14:16

#5521 English quadrant dated 1398 — Dorchester, Dorchester Museum — see the discussion in *London BM Catalogue*, pp. 55-56 (no. 146), and pls. XVII-XVIII; and Ackermann & Cherry, "Three Medieval English Quadrants". nn. 1:5, 6:7

#5522 English quadrant dated 1399 — London, British Museum, inv. no. 60 5-19 1 — see *London BM Catalogue*, pp. 55-56 (no. 146), and pls. XVII-XVIII; G. Turner, "Whitwell's Addition to a 14th-Century Quadrant"; Ackermann & Cherry, *op. cit*., and EPACT. nn. 1:5, 6:7

#5523 Undated English quadrant — London, British Museum, inv. no. 56 6-27 155 — see *London BM Catalogue*, p. 56 (no. 147); and Ackermann & Cherry, *op. cit*. nn. 1:5, 6:7

#5524 Horary quadrant and universal horary dial attributable to Hans Dorn *ca*. 1480 — Bielefeld, Kunstgewerbesammlung der Stadt, Stiftung Huelsmann, inv. no. HW 97 — published in *Bielefeld Catalogue*, pp. 69-70 (no. 9) 10:4, Figs. 10c-d

#7315 Vertical sundial for Damascus and Aleppo by Abu 'l-Faraj ʿĪsā dated 554 H [= 1159/60] — Paris, Bibliothèque Nationale de France, inv. F. 6909 (7315) — see Casanova, "Cadran solaire syrien"; and *Paris IMA 1993/94 Exhibition Catalogue*, pp. 436-437 (no. 332), and now **XIVb-1** and also **IV-7.4**. n. 14:3

#8500 11th-century two-dimensional instrument bearing orthogonal projection of the main markings on the celestial sphere — Regensburg, Stadtsmuseum — see Zinner, "Lehrgerät", and **VIII-3**, corresponding to King, "Aspekte", p. 140-141, and **Fig. VIII-3.3**. n. 15:2

Other manuscripts cited:

MSS Cairo MR 40-41 and J 635 — collection of treatises copied by Muṣṭafā Ṣidqī *ca*. 1740 n. 11:1
MS Istanbul Topkap1 Ahmet IIII 3342 — contains al-Sijzī's treatise on astrolabe construction n. 13:10
MS Istanbul Yeni Cami 784,2 — astronomical handbook of Ḥabash n. 5:4

Part XIIIa-e

Selected early Islamic astrolabes

a) The neglected astrolabe—A supplement to the standard literature on the favourite astronomical instrument of the Middle Ages
b) The oldest astrolabe in the world, from 8th-century Baghdad
c) The earliest astrolabes from Iraq and Iran (*ca*. 850 to *ca*. 1100)
d) A medieval Italian testimonial to an early Islamic tradition of non-standard astrolabes
e) The origin of the astrolabe according to the medieval Islamic sources

Notes:
In **XIIIa** I have inserted various references to standard features of astrolabes so that these are included here once and for all time. A certain amount of repetition of the information contained in **X** could not be avoided without disturbing the integrity of the individual studies. In **XIIIb-d** I have removed the inevitable sections on "What is an Astrolabe?" and most references to my catalogue of medieval instruments currently in preparation (see **XVIII**).

Part XIIIa

The neglected astrolabe

A supplement to the standard literature
on the favourite astronomical instrument
of the Middle Ages

To the memory of Alain Brieux

DEDICATION,
ACKNOWLEDGEMENTS AND NOTES TO THIS VERSION

> "It was his desire to understand more of the objects that now increasingly occupied his time that led Brieux first to more detailed study of mathematics and astronomy, and then to the study of Arabic. From 1960 onwards, when [the French Arabist] Gaston Wiet suggested to him that he undertake a supplement to L. A. Mayer, *Islamic Astrolabists and their Works*, Geneva, 1956, he devoted much of his leisure to the task, travelling widely in the Near East, North Africa, Europe and America to examine the instruments, and maintaining an extensive scholarly correspondence about them. Faced with the difficulty of finding good photographs for study, Brieux began to take his own, and in this activity also developed a high proficiency. At the same time his earlier interests were not forgotten. In 1965 he published a long poem "Le Château de Prague", and in 1970 a volume of collected poems, besides a number of learned studies. All this took place at the same time as his stature was growing in his profession, especially after his exposure of a series of important auction sales, culminating in that of the Leonard Linton collection in 1980, made severe demands upon his time. In 1981 Alain Brieux was elected a corresponding member of the Académie Internationale d'Histoire des Sciences." Anthony Turner, "Alain Brieux" (1986), p. 186.

> "In 1972 Alain was visited by an Englishman offering old scientific instruments which supposedly had been found in his grandmother's attic. He bought several but when he was offered a semi-circle by Michel Coignet which was well-known from a book illustration, he became suspicious. He kept the instrument on approval, and through careful study of the object and metal analysis discovered that it had been made recently. Realizing that perhaps he was on to a major fraud, he contacted Scotland Yard. Subsequent police investigations showed that the forgeries had been made in England and that there were many more. These forgeries drew international attention and the maker was convicted at the Old Bailey." Willem Mörzer Bruyns, "Alain Brieux" (2001), p. 706.

This study is dedicated to the memory of Alain Brieux (1922-1985), the owner of the well-known *librairie* in the Rue Jacob in Paris, dealer *par excellence* in scientific instruments, gentleman-scholar, humanist and poet. For those who never had the privilege of knowing the man, the sentiments expressed by Anthony J. Turner in his *éloge*, "Alan Brieux (1922-1985)", *Nuncius* 1 (1986), pp. 185-187, and Willem F. J. Mörzer Bruyns on his legacy, in "Alain Brieux, Dealer and Scholar in Paris: His Archive on Scientific Instruments", *ibid*. 16 (2001), pp. 703-709, must suffice.

Several of the instruments described in this volume (especially **XIIIc**) were formerly in the collection of Alain Brieux, and he alone at the time recognized their significance. Others could read the inscriptions better and others knew better how they worked, but Alain had a *feel* for instruments second to none in those days, and he simply *knew* what he had in his hands. Alain helped me considerably at the beginning of my researches on Islamic instruments in the mid 1970s, not least with the provision of photos of this instrument or that (such as the astrolabe-equatorium of Hibatallāh). Well I remember staying overnight in his photo studio in Paris in the mid 1970s, surrounded by all sorts of silver umbrellas, and going with him to one of his favourite bistros just to talk about Islamic instruments. This was quite a treat for a lad from Cairo.

One of Alain's dreams was to publish a *Répertoire* of Muslim instrument-makers and their works to replace the standard work of L. A. Mayer (*Islamic Astrolabists and Their Works*, 1956). Together with Francis Maddison of Oxford, he put together an enormous volume of materials that have yet to appear in print, but the end is in sight, not least thanks to the undaunting efforts of Alain's widow, Dominique.

Dominique has valiantly kept the *librairie* going until the present time, although shortly that era will end, and we shall become neighbours. In the early 1990s she kindly provided me with a set of photos that were left over from the *Répertoire*. And it was Dominique who asked me "*il s'agît de quel astrolabe*?" in my paper entitled "The Neglected Astrolabe"; the answer, which does sound a bit arrogant, was: "*tous les astrolabes médiévaux*".

Some parts of this study dealing with *Islamic* astrolabes appeared originally as "The Neglected Astrolabe", in *Mathematische Probleme in Mittelalter—Der lateinische und arabische Sprachbereich*, Menso Folkerts, ed., Wiesbaden: Harrassowitz, 1996, pp. 45-55, in the proceedings of a conference on medieval mathematics held at the Herzog-August-Bibliothek in Wolfenbüttel in June, 1990. I have added materials on medieval *European* instruments from *The Ciphers of the Monks*, pp. 359-363 (Appendix G: The principle and use of the astrolabe), and 364-379 (Appendix H: On medieval European astronomical instruments).

This is not the place for an introductory account of the astrolabe. The reader will surely have access to at least some of the various studies listed in n. 2 below, some of which ignore the surviving instruments. Also a new English study of the astrolabe by Jim Morrison (www.astrolabes.com) is currently being completed, and should be available soon. The basic references given in this study are not repeated in the astrolabe descriptions that follow in **XIII-XV**.

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1 The principle and use of the astrolabe

"The greatness of the Astrolabe is due to the fact that, like other great scientific apparatus, it is the result of a combination of many discoveries and inventions. It is the product of the human mind acting simultaneously in several directions, which, aided by the mechanical skill of generations of instrument makers, has created a new organ by means of which previously laborious operations have been simplified and new paths have been cleared for future progress." Robert T. Gunther, *The Astrolabes of the World* (1932), I, p. v.

"The astrolabe was essentially an instrument for measuring the angular distance between two objects, and thus it could be used for taking the elevation of a heavenly body. ... The astrolabe was most convenient in tropical latitudes where the variation in the altitude of the sun is great, and for this reason it was much used by the Arabs; ... . Arabic astrolabes ... do not show much development compared ... with later Western ones, especially in the 16th century." Alistair C. Crombie, *Augustine to Galileo* (1952), I, p. 107.

"The astrolabe made it possible to read off longitude and latitude with the aid of its dioptra." Hans-Wilhelm Haussig, *History of Byzantine Civilization* (1971 English translation from the 2nd German edition of 1966), p. 122. [Not one word about the sole surviving Byzantine astrolabe of 1062, perhaps just as well.]

"The ability of Islamic civilization to perfect what it inherited, and to endow what it made with beauty, is nowhere better expressed than in the astrolabe." Oliver Hoare in *Riyadh 1985 Exhibition Catalogue*, p. 81.

"Conçu à l'origine pour déterminer les hauteurs des étoiles au-dessus de l'horizon, l'astrolabe s'est progressivement transformé en un instrument de navigation compliqué, empruntant les symboles de sa décoration à la tradition astronomique." Ivars Peterson, *Chaos* (1993/95), p. 41. [Such chaotic descriptions of the astrolabe abound in the popular and scholarly literature. The astrolabe was never used in navigation.]

"A 9th-century astrolabe from Iraq used to decipher the celestial mechanism that was said to govern life on earth." An absurd caption to an illustration of an astrolabe from 10th-century Baghdad (appropriately, in this case, with the alidade attached to the front) in *Concise Encyclopaedia of the Middle Ages* (1989/1991), p. 40. [Such nonsense is unexpected in a serious scholarly publication.]

"Like the modern electronic computer, the astrolabe in the Middle Ages was a source of astonishment and amusement, of annoyance and incomprehension. Imprecise as the astrolabe may have been in practice, it was undoubtedly useful, above all in judging the time. The instrument might have been used, more often than not, in the dark, but 'dark' is hardly the word to describe the age in which it was so widely known and so well understood." John D. North, "The Astrolabe" (1974/1989), p. 220 (reprint).

"Fer la història de l'astrolabi pla és una mica com fer la història de l'astronomia o, almenys, d'un dels seus aspectes més destacats." Josep Chabàs & Daniel Bosch, *L'astrolabi pla* (1987), p. 9.

"The astrolabe, the most important astronomical instrument of the Middle Ages, was designed to measure the altitude of the stars, moon or sun without any mathematical calculation [!]. It was used in much the same way as the astronomical quadrant or sextant [!], but in addition it bore various diagrams [?] or scales [?] which made it possible to determine immediately the positions of the sun, moon, and planets [!!]—most significant, the earth [!!!]—in relation to the fixed stars." J. Michael Rogers in *Washington LC 1992 Exhibition Catalogue*, pp. 215. [Exhibitions are well advised to keep astrolabes out of the hands of art historians.]

"Weshalb interessieren Sie sich für Astrolabien? Sie sind doch Professor." Comment made to the author by a (junior) curator of scientific instruments in a German museum, Summer, 1991.

For the purposes of ancient and medieval astronomy, and for many other purposes, it is useful to imagine the heavens on a sphere about the observer. That celestial sphere appears to rotate with respect to the horizon and meridian of the observer, which together provide a fixed frame

enclosing the sphere. The apparent rotation is about a celestial axis, whose position is dependent on the latitude of the locality of the observer. With such an arrangement, one can simulate the apparent daily rotation of that sky about the observer and his horizon. We further conceive the celestial equator and the ecliptic on the sphere, and with the rotation of the sphere about the celestial axis, all celestial bodies appear to move in small circles parallel to the celestial equator. The day-circles of the sun, which are limited by the day-circles at the solstices, depend on the position of the sun on the ecliptic. This model also enables us to control the position of the ecliptic relative to the horizon and meridian.[1] The astrolabe—the most popular instrument of the Middle Ages—achieves all of the above in two dimensions.[2]

The astrolabe is thus a two-dimensional model of the three-dimensional celestial sphere, reduced to a plane by a mathematical projection known as stereographic. The theory of stereographic projection dates back to Hipparchus (about 150 B.C.). The projection is achieved in the plane of the celestial equator so that the centre represents the celestial pole and clockwise rotations correspond to rotations of the celestial sphere. The projection is effected from the south celestial pole, for it is the northern sky that is of interest to an observer in the northern hemisphere: on the standard astrolabe the projection is bounded by the circle corresponding to the outermost reaches of the sun from the celestial pole, that is, by the circle corresponding to the Tropic of Capricorn.

The standard astrolabe consists of two main parts. The celestial part, called the rete, is in the form of a perforated frame with pointers representing various fixed stars and an excentric circular ring representing the ecliptic. The terrestrial part, called the plate, bears markings for a specific latitude, including the horizon and the meridian, as well as altitudes above the horizon and azimuths around it. The celestial part can rotate over the terrestrial part, very much as it appears to do in reality. A different plate is needed for each terrestrial latitude, and the set

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[1] On these notions see Aaboe, *Episodes*, B, pp. 1-23 ("What every young person should know about naked-eye astronomy"). On the origins of these notions see now Brack-Bernsen, "The Oblique Great Circle".

[2] Important basic studies on the astrolabe are listed as Hartner, "The Astrolabe", A-B, and Michel, *Astrolabe*. Lehr, *De geschiedenis van het astronomisch kunstuurwerk*, pp. 111-131, contains a useful section on the geometry of stereographic projection. The best introductions to the astrolabe in English are still North, "The Astrolabe", and *Greenwich Astrolabe Booklet*. See also García Franco, *Astrolabios en España* (in Spanish); Poulle, "L'astrolabe", and d'Hollander, *L'Astrolabe* (in French); Chabàs & Bosch, *L'astrolabi pla* (in Catalan); King, "Nürnberger Astrolabien", I, pp. 101-114, and Stautz, *Munich Astrolabe Catalogue* (in German); and Trento, *Astrolabio* (in Italian). The last-mentioned is a most useful addition to the literature, with many illustrations of historical interest. A new book in English by Jim Morrison is in the final stages of preparation (see www.astrolabes.com); see already his "The Electronic Astrolabe". Astrolabe "kits" are listed as *Greenwich Astrolabe Booklet* and *Chicago Astrolabe Booklet*. A survey of this popular literature and some critical remarks about one of the least successful books on the subject is in G. Turner, "Review of d'Hollander, *Astrolabes*".

Useful catalogues dealing with all aspects of several instruments, except the technological ones, are García Franco, *Astrolabios en España*; Gibbs & Saliba, *Washington NMAH Catalogue*; King, "Nürnberger Astrolabien"; Stautz, *Munich Astrolabe Catalogue*; and, most recently *Chicago AP Catalogue*.

It should be mentioned that, contrary to many claims in the tertiary literature, the astrolabe was not used in navigation. Unfortunately, other instruments that had nothing to do with our neglected astrolabe were also called "astrolabes". One was the so-called "mariner's astrolabe", which is nothing other than a device for measuring celestial altitudes: see Stimson, *The Mariner's Astrolabe*. A valuable, more recent study is Maddison, "Origin of the Mariner's Astrolabe". Another was a "plane table" for surveying, being nothing more than a graduated circular horizontal plate fitted with an alidade. Such is the "astrolabe" of Tobias Mayer (Germany, mid 18th century): see Forbes, "Tobias Mayer's New Astrolabe".
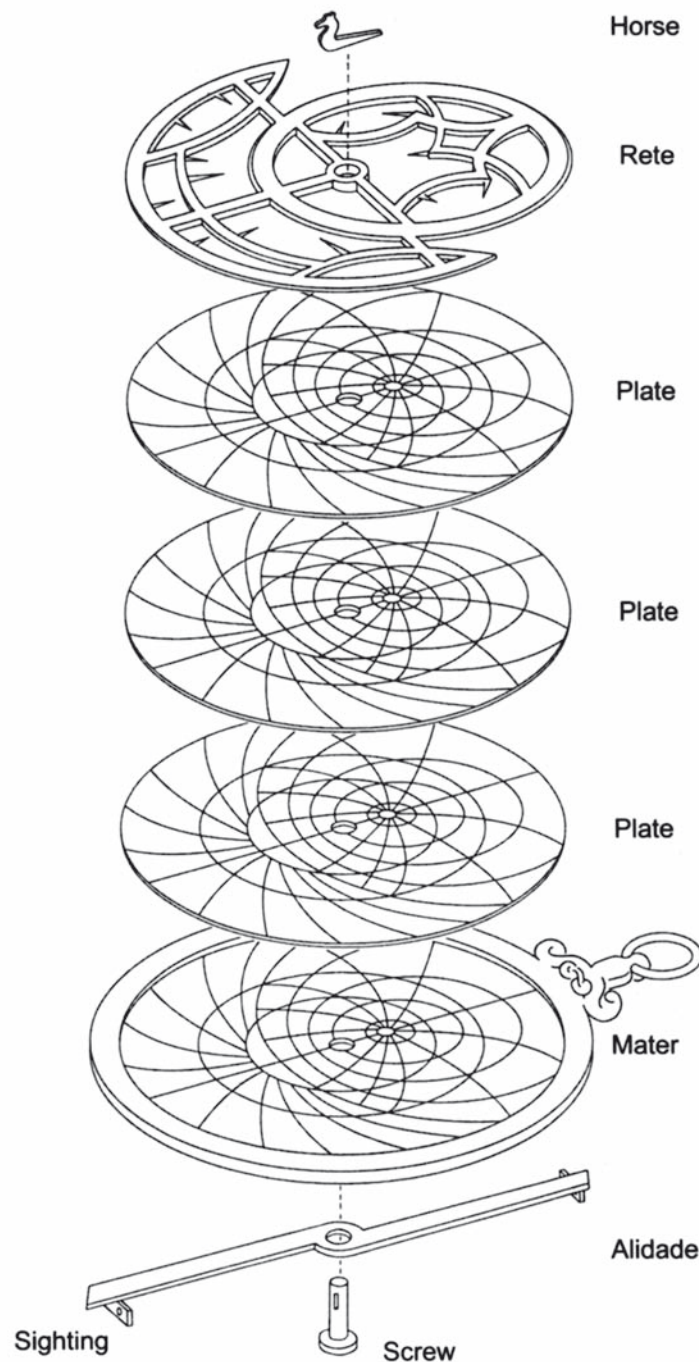
Fig. 1.1: The components of the standard astrolabe. The rete fits over the plates, which fit into the mater. The plates are held in position by pegs that fit into a hole inside the rim of the mater, and the rete is free to be rotated over the appropriate plate. Three plates are shown here, whose six sides, together with the mater, can be engraved with markings for the seven climates. The ensemble is held together at the centre by a pin, which is fitted with a wedge, often in the form of a horse's head. [From King, *The Ciphers of the Monks*, p. 361, originally adapted, with permission, from North, "The Astrolabe".]

Fig. 1.2: The rete shows the positions of various fixed stars, indicated by named pointers, and the path of the sun, known as the ecliptic, represented by an excentric ring divided for the signs of the zodiac. This particular rete is from the earliest surviving astrolabe from al-Andalus, perhaps as early as the 10th century (#110 = #135). Alas, the piece is unsigned and undated, but, by way of compensation, it has additional, but still medieval, markings by an Italian (witness the form SAGIPT). The rather simple rete is in the style of ʿIrāqī astrolabes from the 10th century (see **XIIIb-c**) and resembles the rete of a contemporaneous Andalusī astrolabe illustrated by a European (see **Fig. 9.2a**). See **Fig. 1.3** for a plate from this astrolabe. [Courtesy of The British Museum, London.]

of plates for different latitudes with the rete on top fits inside a frame known as the mater, which also provides a circumferential scale for the ensemble: see **Fig. 1.1**.

The rete features a horizontal (equinoctial) axis and sometimes a vertical (solstitial) axis, and it is bounded by a circular frame (corresponding to the Tropic of Capricorn). In the upper part of the central space is a circular frame corresponding to the ecliptic, which is divided counter-clockwise according to the signs of the zodiac. The vernal equinox, or beginning of Aries, is on the left of the ecliptic scale, at the intersection with the equinoctial axis, and the

autumnal equinox, or beginning of Libra, is at the corresponding point on the right. The summer solstice, or beginning of Cancer is at the lower limit of the ecliptic, and the winter solstice, or beginning of Capricorn, is at the uppermost limit. The outer frame is usually open at the top so as not to interfere with this part of the ecliptic. There is usually an additional frame below the ecliptic, corresponding roughly or exactly to the circle of the celestial equator. This serves to strengthen the rete (if it is connected to the ecliptic as well as the outer frame) and to provide a base for star-pointers.

There is a great deal of work remaining to be done on the stars featured on astrolabes. The early instruments presented in **XIIIc** hardly give any idea of the complexity of the situation, although al-Khujandī (**XIIIc-9**) already goes far beyond the 17 stars of Greek and early Islamic astrolabes. Later ones, such as those in **XIVd-2** and **XIVe-1**, reveal that Muslim astrolabists ventured far beyond the initial 17 stars of Greek astrolabes and did not rely on al-Ṣūfī's list of 44 astrolabe stars. In some cases, stars were selected to maintain the symmetry of the pointers with respect to the vertical axis of the retes; over several centuries, different sets of stars would satisfy this criterion. The complexity of the situation is well revealed by the fact that the Yemeni Sultan al-Ashraf (**XIVa**) presents two different lists of astrolabe stars and on his surviving astrolabe he uses a third set of stars. The writings of Paul Kunitzsch, based mainly but not exclusively on the manuscript tradition, represent a sound foundation for further research on this fascinating topic. However, of all the available star catalogues, only those of al-Ṣūfī and Ulugh Beg have attracted much attention. Only in the past few years has an edition of the star-table compiled by the astronomers of the Caliph al-Maʾmūn in the middle of the first half of the 9th century been published.

Astrolabic plates for different latitudes developed from the ancient Greek notion of providing a separate plate for each of the seven climates of classical geography, thus ensuring that the instrument remained 'universal' in its application.[3] The earliest surviving Eastern Islamic astrolabe and also the earliest known Western Islamic astrolabe have plates for the climates, as do some of the earliest European astrolabes. But there was also a tendency, attested already on the only surviving astrolabe with Greek inscriptions and dated 1062 (see below), to choose latitudes of important localities for the plates. Thus, the plates on an Islamic astrolabe might serve a string of latitudes corresponding to certain local urban centres, as well as, perhaps, Mecca and Medina. In the same way, medieval European astrolabes might serve a string of latitudes for localities in the cultural region of the maker, as well as, perhaps, Jerusalem. Alongside the latitude, the length of longest daylight may be stated, underlying which will be a value of the obliquity of the ecliptic.[4]

On each plate, the local meridian is the vertical diameter, and the perpendicular diameter is also drawn. There are three base circles corresponding to the Tropic of Cancer on the inside, the celestial equator in the middle, and the Tropic of Capricorn on the outside. There are two other main sets of markings, corresponding roughly to the upper and lower halves of the plate.

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[3] On this see King, "Geography of Astrolabes", now in **XVI**.

[4] On the possible values of the obliquity of the ecliptic underlying the associated lengths of longest daylight see the *EI*$_2$ articles "Mayl" [= declination and obliquity] and "Minṭaḳat al-burūdj" [= ecliptic]. On the lengths of daylight for specific latitudes, see also King, *Mecca-Centred World-Maps*, pp. 75-76.
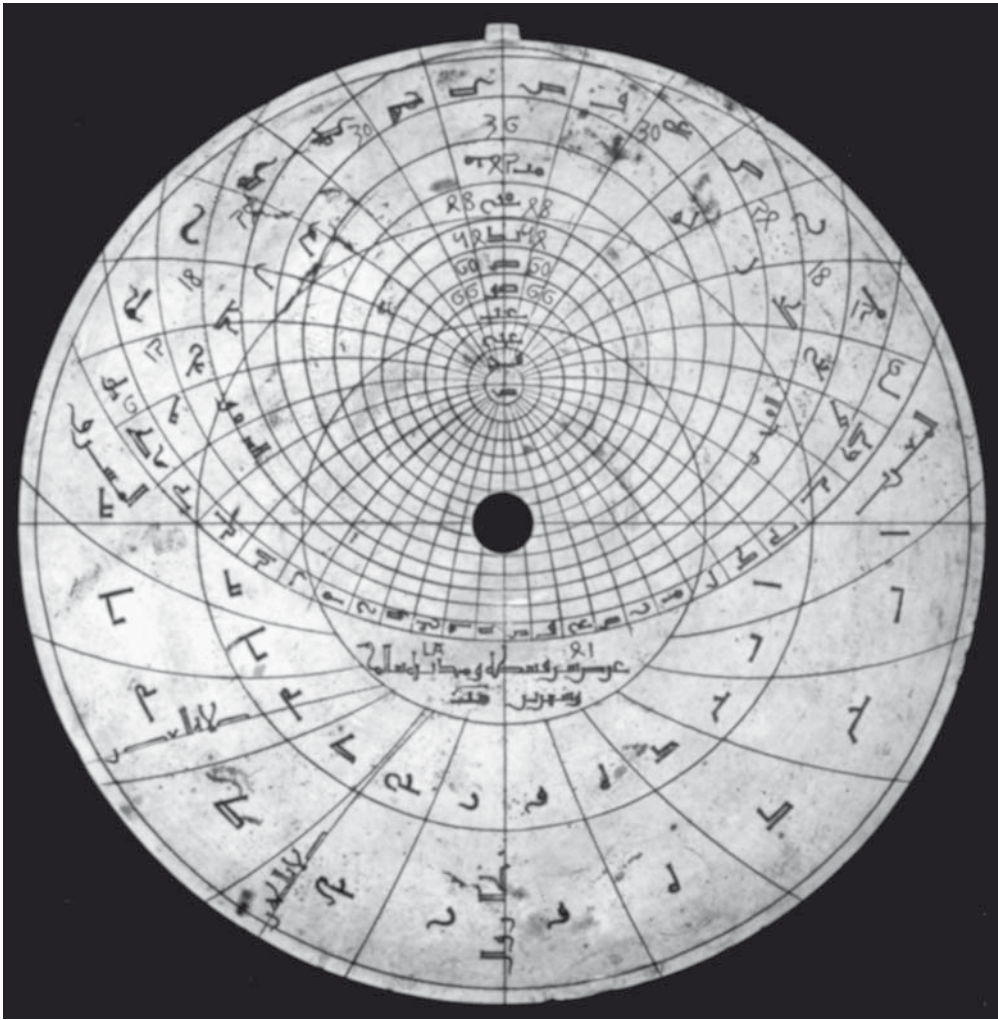
Fig. 1.3: One side of a plate from the astrolabe shown in **Fig. 1.2**. There are altitude circles for each 6° and azimuth circles for each 10°. The Arabic inscription informs us that the latitude served in 42°, and that the maker had Saragossa, Medinaceli and Santarém in mind. The medieval Italian who added markings to this piece interpreted the latitude as 41°. The altitude circle for 18° is marked for the prayers at daybreak and nightfall (for these, one uses the ecliptic longitude opposite that of the sun). Amongst the markings for the seasonal hours below the horizon we find special curves for the *ẓuhr* and *ʿaṣr* prayers (in al-Andalus the former was defined in terms of shadow lengths, which explain why it is so late—about two hours—after midday). [Courtesy of The British Museum, London.]

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Fig. 1.4: The back of an astrolabe by Aḥmad ibn Ḥusayn ibn Bāṣo of Granada dated 704 H [= 1304/05] (#144). Some of the Arabic inscriptions have been rendered in medieval Latin by an Italian (note the OTO for October). Around the upper rim are two altitude scales. Inside these are two scales linking the passage of the sun around the ecliptic to the Western months. The equinox is at March 13.5, which is more appropriate for epoch 1200 than 1300. Note that the inner scale is not concentric with the outer one, which is also in order. Below the horizontal diameter is a double shadow-square to base 12, and the vertical and horizontal shadows for reasonable solar altitudes are also displayed on the (unique kind of) shadow scales on the lower rim (see **XIIb-A**). Above the horizontal diameter is an inscription identifying the maker and stating the year of construction. [Private collection; photo courtesy of the owner.]

LIBRA
SCOR
SAGI
CAPRI
AQVA
PISIS

The upper markings show the horizon as an arc of a circle passing through the intersections of the east-west line, that is, the horizontal diameter, with the celestial equator. Above this is a series of arcs of circles decreasing in radius up to a point that corresponds to the zenith, or point directly overhead. These are the altitude circles, and they may be engraved for each 1°, 2°, 3°, 4°, 5° or 6° of argument.[4a] An orthogonal set of arcs of circles emanating from the zenith and reaching down to cut the horizon at right angles are the circles of azimuth, or direction measured around the horizon, and they may be represented for each few degrees. The arguments are usually marked on each set of circular arcs. Below the horizon there may be a curve representing the angle of depression of the sun below the horizon at nightfall or daybreak. On Islamic astrolabes, these may labelled for the associated prayers, the *ʿishāʾ* and the *fajr*. Sometimes these times are marked above the horizon, in which case to use them one must work with the opposite point of the ecliptic from the sun's longitude.

Also, below the horizon, there is a set of arcs of circles representing the seasonal hours. These curves divide the arcs of the three base circles below the horizon into 12 equal parts. The seasonal hours, one-twelfth divisions of the length of daylight throughout the year, were in standard use in Antiquity and the Middle Ages.[5] They vary according to the local latitude and the time of the year. Amidst these markings on Islamic astrolabes we sometimes find additional markings for the *ẓuhr* and *ʿaṣr* prayers.[6] Equinoctial hours, or 24th divisions of the length of day and night, as we use today, were used by astronomers in the Middle Ages, and are represented on the astrolabe by a rotation of the rete over a plate by an amount of 15° (= 360°/24). They are sometimes marked on the rim of the mater of the astrolabe.

The back of the mater on the standard astrolabe bears one or two altitude scales on its upper rim and is fitted with a sighting device called an alidade attached at the centre. With these, one can measure solar or stellar altitudes. For timekeeping at night, one can then use the appropriate star-pointer on the rete, but for the sun, one first needs to know whereabouts the sun is on the ecliptic. For this purpose, calendrical and zodiacal scales may be available on the back of the mater to show the solar longitude in terms of the date in the Julian calendar. Since the earth's orbit around the sun is not circular, the sun's motion viewed from earth is not regular. This irregularity is controlled on the astrolabe either by making the calendrical scale non-concentric with the outer solar scale or by making it concentric but with non-uniform divisions. From such a scale, one can immediately read the solar longitude on any day of the year, or, for example, the date of the equinox. Knowing the solar longitude for the day in question one can then find the corresponding point on the ecliptic on the rete.[7]

Additional markings inside the upper area of the back bounded by these two scales often include a set of arcs of circles that enable the user to calculate the time of day in seasonal hours for any terrestrial latitude. These markings were devised in Baghdad in the 9th century

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[4a] On a medieval Latin treatise labouring the point see Kunitzsch, "Six Kinds of Astrolabe".

[5] On the seasonal hours see the references cited in n. 4 to **III-1.1**.

[6] These no longer coincide with the seasonal hours with which their standard definitions, dating from the 8th century, were originally associated: see **III-1.2** and **IV-2**.

[7] For various reasons it is dangerous to try to date any instrument by the correspondence of the solar and calendrical scales. See the references in n. 37 below.

to solve graphically an approximate Indian formula for timekeeping.[8] They are easy to engrave and were still being put on the backs of astrolabes in Europe in the 17th century, long after their origin (and, in some cases, also their original purpose) had been forgotten. They serve to determine time of day quite reasonably in the latitudes of the Eastern Mediterranean but not in those of Northern Europe.

Below the horizontal diameter on the back is usually a single or a double shadow square, consisting of a set of horizontal and vertical scales for measuring shadow lengths corresponding to solar altitudes measured on the upper altitude scale diagonally opposite. The former measure horizontal shadows of a vertical object and the latter vertical shadows of a horizontal object. At solar latitude 45° both shadows are equal to the length of the object casting the shadow, invariably taken as having length 12 "digits", sometimes also, on a different scale, 7 "feet".[9] These shadow scales were also devised in Baghdad in the 9th century and were standard on astrolabes through to the Renaissance.[10]

Besides having a scientific function, the astrolabe can be an object of beauty. It is the rete or celestial part of the instrument that provides the main aesthetic appeal. Often the horizontal (equinoctial) and vertical (solstitial) bars are counter-changed in various places along their length. Rete-design depended on which individual stars needed to be portrayed, and special features were introduced to reduce the lengths of various star-pointers. Popular on Western Islamic astrolabes were frames in the form of *miḥrāb*s along the lower rim. Very popular on medieval European astrolabes were half-quatrefoil designs at the ends of the horizontal axis and full quatrefoils on the upper part of the vertical axis; these provide useful means both of strengthening the rete and of making areas of the heavens accessible with shorter star-pointers than would be needed if the pointers were attached to the basic frames of the rete. This very Gothic quatrefoil seems to have been influenced by early Islamic astrolabes, in turn perhaps copied from Byzantine retes.[11] Particularly on Italian and French retes there is usually a short bar inside the upper (southern) half of the ecliptic to mirror and counterbalance the more substantial lower equatorial frame. This again may be the result of Islamic influence.[12]

While some astrolabes are large and bear mathematically accurate markings (the largest known is about 2.15 m in diameter, no longer suitable for putting in one's pocket), others may be quite small (the smallest known is 49 mm in diameter).[13] However, the vast majority of these instruments were not used for practical purposes; rather they became collectors' items already in the Middle Ages.

The uses of the astrolabe are nevertheless manifold. The astronomer ʿAbd al-Raḥmān al-Ṣūfī (Shiraz, *ca*. 965) identified over 1000 operations that one could perform with it.[14] Having just made a measurement of the altitude of the sun or a specific star, one places the point of

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[8] On the universal horary quadrant see now **XIIa**, and on the approximate formula see also **XI**.
[9] On these bases see **I-1.1** (p. 25), **II-1.3** (p. 211), and **III-1.2** (p. 469) and the references there cited.
[10] On shadow-scales see now **XIIa-A**.
[11] See now **XVII**.
[12] See **XIVc**.
[13] On the diameters of astrolabes see Price *et al*., *Astrolabe Checklist* (see n. 29 below), pp. 69-84.
[14] See Destombes & Kennedy, "al-Ṣūfī on the Astrolabe", for a list of the chapter-headings.

the ecliptic corresponding to the position of the sun or the appropriate star-pointer on top of the altitude circle corresponding to the observed altitude on the plate serving the observer's latitude. Care must be taken whether one is dealing with altitudes in the eastern or western sky (left and right side of the meridian, respectively). Then the configuration of the rete on top of the plate mirrors the instantaneous configuration of the heavens with respect to the local horizon and meridian. Two successive configurations can be used to measure the passage of time. One can, for example, rotate the rete until, say, the sun is on the western horizon: the amount of rotation indicates the time remaining until sunset (by day) or the time elapsed since sunset (by night). Or one can move the sun from the horizon to the twilight curve and investigate the duration of twilight. Or one can tell at a glance for any celestial circumstance which point of the ecliptic is simultaneously rising over the horizon and inspect the configuration of the ecliptic with respect to the horizon and meridian. Since this configuration was thought by the credulous to be of significance in the affairs of men, this use of the astrolabe was of prime importance in astrology. The horary markings on the back enable the user to find the time of day approximately with facility, and the procedure works for any latitude. No solar longitude scale is necessary although these sometimes appeared on European astrolabes. The shadow-squares can be used for surveying, although here a large instrument is preferable. Only one astrolabe is known that has four shadow-squares on the back (namely, the Byantine astrolabe #2, on which see **4** below), thus corresponding to the so-called "plane table" of the surveyors, when the instrument is held front down parallel to the ground.[15] Sometimes we find a universal sundial on the alidade, a very approximate device going back to the 9th century in the Islamic context, but attested also in late Antiquity.[16]

2 Historiographical remarks

> "Gunther's monumental *The Astrolabes of the World* (1932) was the most ambitious published result of his archaeology of science, the first such study of a corpus of non-optical scientific instruments. Its origins lie in the comparative study of the Oxford and Evans astrolabes before 1919, by way of volume II of *Early Science in Oxford*; and he set about preparing it in the very month that the Museum opened. Inevitably with such a pioneering work, fifty years have revealed many inaccuracies, especially in its eastern volume. But those who can now improve upon Gunther's achievement have developed their knowledge from the foundations which he built ... . It should never be forgotten that Gunther's books are footnotes to a greater work—the Museum of the History of Science. Writing *The Astrolabes of the World* was 'an act of piety' both to Lewis Evans, and 'to the University which has enabled me to realize (in part) my ideal of a Restoration of Charles II's old and neglected Ashmolean as a public Museum of Science'. Note the mild polemic, the joke (a capital R), and the historical conceit (Charles II)." Anthony V. Simcock, ed., *Robert T. Gunther*, p. 82).

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[15] Indeed, it was from the Arabic term *al-ʿiḍāda* (whence our "alidade") that, by a gross distortion, the mysterious (and otherwise unexplained and inexplicable) word "theodolite" was coined. See the remarks in G. Turner, *Elizabethan Instruments*, p. 73, which merit pursuing, although Turner, inevitably, dismisses any connection with the Arabic.

[16] See now **XIIa-B**.

a) Islamic astrolabes

The state of our knowledge of medieval *Islamic* astronomical instruments in general and astrolabes in particular was until a few years ago very much a matter of chance.[17] For example, two dozen Eastern astrolabes from *ca*. 800 to *ca*. 1100 are all that remain of the hundreds or even thousands that must have been made during the formative period of Islamic science, and only about one-third of these had been satisfactorily published.[18] Dozens of treatises on the construction and use of the astrolabe written during this period attest to the popularity of the instrument but only a few are available in published form; for the most important treatises (namely, those of al-Khwārizmī, al-Farghānī, al-Sijzī and al-Bīrūnī) we still have to resort to the manuscripts. Again, only a fraction of the several hundred astrolabes surviving from the period 1200-1900 (which all qualify as "medieval" within the context of Islamic science) had been published.

Robert T. Gunther's descriptions of *Islamic* astrolabes in volume 1 of his monumental *Astrolabes of the World*, published in 1932, are marred by numerous errors and has long been out of date: he listed less than one-half of the earliest Islamic astrolabes and less than one-third of all such astrolabes now known. Leo A. Mayer's commendable survey of Islamic astrolabists and their works (Geneva, 1956) introduced much new material, and the long-awaited *Répertoire* of the late Alain Brieux of Paris and Francis Maddison of Oxford promises to revive some interest in this field. The *Répertoire* is arranged alphabetically by makers' names and contains only the most basic information on each signed instrument, so its appearance will not obviate the need for a comprehensive publication on all the available instruments. This should be conducted in the light of contemporary texts and, no less, in the light of the colourful regional developments in astronomy that occurred in the main cultural regions of the Islamic world roughly from the 11th century onwards. We now have a clear picture of these regional developments, and can identify, for example, (Mamluk) Syrian and Egyptian, (Rasulid) Yemeni, Maghribī, (Timurid and Safavid) Iranian, and (Ottoman) Turkish astronomical traditions, of which instrumentation constitutes a small, yet significant, part.

b) Medieval European astrolabes

For medieval Europe, the situation is quite different, for we have, as yet, very limited control over regional schools of astronomy, let alone regional schools of instrumentation. The documentation of medieval *European* astrolabes still leaves much to be desired. Some 45 European astrolabes dating from the period 1200-1500 were discussed by Robert T. Gunther in volume 2 of his monumental *Astrolabes of the World*, and very few such instruments have been published since.[19] The number now known is over 150. The number actually made must

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[17] The best descriptions of individual Islamic astrolabes are Morley, *Astrolabe of Shāh Ḥusayn*; Woepcke, "Arabisches Astrolabium"; Sarrus, "Astrolabe marocain"; Frank & Meyerhof, "Mogulisches Astrolab"; and Helmecke, "Das Berliner Astrolab des Muḥammad Zamān".

[18] See now **XIIIb** and **c**.

[19] See especially Tomba, "Astrolabi", A-D; *Rockford TM Catalogue*, pp. 29-57 (deficient on star-names); King & Turner, "Bessarion's Astrolabe"; King & Maier, "London Catalan Astrolabe"; Glasemann, "Zwei mittelalterliche französische Astrolabien"; King, "14th-Century Astrolabe from Christian Spain", now in **XV**; and *idem*, "Urbino Astrolabe". Various individual auction catalogue entries could also be mentioned, notably *Christie's*

have run into the thousands—the vast majority of the surviving instruments are the sole productions of their makers known to us, but again most of these were clearly not individual one-shot productions. And there are vast gaps in our knowledge, some of which can be filled by the available medieval manuscripts on the construction and use of instruments.[20]

Gunther's pioneering work on European instruments is arranged according to geographical provenance, but there are numerous incorrect identifications. Thus, two of his "Italian" astrolabes (#168 and #173) are in fact French and German, respectively,[21] and one of his "Spanish" astrolabes (#164) was made in Vienna.[22] Gunther is hardly to blame for this; as the first to look at these instruments and without direct access to instruments in collections outside England he simply could not have known otherwise. His rendering of medieval European star-names was better than his attempts at Arabic ones, but reading mainly corruptions of Arabic star-names mingled with vulgarised Latin phantasy forms, all in Gothic script, is an exercise that would challenge any medievalist, and Gunther had nothing to build on because very little was known about medieval European star-names at the time. In the last few decades Paul Kunitzsch of Munich has documented medieval star-names as they occur in medieval manuscripts,[23] but he has mainly fought shy of investigating the star-names found on astrolabes, many of which attest to traditions unknown from the manuscript sources.[24]

Gunther's two volumes on Islamic and European astrolabes have remained unchallenged for over 60 years. Nobody has published corrections of any of the mistakes in either of them.[25] Catalogues of a few collections have appeared in the ensuing decades, a minority excellent with full details, some good in many respects but not complete in that star-names and other significant details are omitted, and some simply pathetic. The major collections in Oxford and Florence are still uncatalogued, and for the first of these not even a handlist is available. A few more competent and complete descriptions of various individual astrolabes have been published since the 1950s, namely, by Salvador García Franco for Spanish collections,[26] by Tullio Tomba for astrolabes in Milan and Turin,[27] and by Burkhard Stautz for the astrolabes in Munich.[28] Other articles of widely varying quality are scattered through the literature, but

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London 29.9.1994 Catalogue, pp. 34-39 (lot 136) on the Italian astrolabe #4556 (see the text to n. 84 below).

[20] The earliest European astrolabe treatises are discussed in Van de Vyver, "Traités sur l'astrolabe"; Bergmann, *Innovationen im Quadrivium*; Kunitzsch, "Glossar der Astrolabliteratur", and numerous articles reprinted as *idem*, *Studies*; also Borst, *Astrolab*. Various articles by Paul Kunitzsch are important, including "Messahalla on the Astrolabe", "The Arabic Reception of the Astrolabe", and "The Terminology of the Astrolabe". See now Lorch, "Astrolabe Treatise of Rudolf of Bruges", which surveys the early treatises.

[21] Oxford, Museum of the History of Science, inv. nos. IC 168 and 173, respectively: see Gunther, *Astrolabes*, II, pp. 317-319 (no. 168) and 327-328 (no. 173).

[22] Chicago, Adler Planetarium, inv. no. M-28: see Gunther, *Astrolabes*, II, pp. 311-312 (no. 164), and *Chicago AP Catalogue*, I, pp. 49-52 (no. 4), where this error is repeated.

[23] On the star-names in the textual sources see various studies by Paul Kunitzsch, notably those listed as *Arabische Sternnamen in Europa* and *Sternverzeichnisse*. See also nn. 30-31 below.

[24] See the text to n. 32 below.

[25] Some of the problems in the work are discussed in Gingerich, "Review of Gunther Reprint".

[26] García Franco, *Astrolabios en España*. This valuable work, long out-of-print, should be reprinted with decent photographs.

[27] Listed as Tomba, "Astrolabi", A-D.

[28] Stautz, *Munich Astrolabe Catalogue*.

Gunther is still "the standard work". This, then, is—or rather, was until recently—the state of basic documentation in the field of medieval instruments.

c) The Frankfurt catalogue

For some years, I have been conducting a survey of all Islamic astronomical instruments and all European instruments to *ca*. 1550. Particular attention is being paid to the stars represented on the retes, the markings on the plates, the scales and grids, as well as to the inscriptions, and decorative features are not being overlooked. Contemporary texts on the construction and use of these instruments are also being investigated. The descriptive sections on early astrolabes (800-1100), later Iraqi and Iranian astrolabes in this early tradition (up to about 1500), Egyptian, Syrian and Yemeni astrolabes (1200-1800), later Andalusī and Maghribi (1200-1500) astrolabes, as well as Ottoman Turkish instruments (1500-1900) are essentially completed. The documentation of later Maghribi, Persian and Indian astrolabes (necessarily restricted to the most significant) has been considered less urgent than the documentation of early European instruments with Latin and Hebrew inscriptions, which is still in progress. My documentation of medieval European astrolabes includes descriptions of most pieces up to *ca*. 1500, many of the early descriptions already in need of revision.

In view of the fact that the *Répertoire* of Brieux and Maddison, with its rich photographic archive, has not been published yet, I have held back on the publication of any parts of the Frankfurt catalogue until the present volume, in which I include the earliest Islamic astrolabes (**XIIIb-c**). I resisted the temptation to include here the next batch, that is the 16 or so Andalusī astrolabes from the 10^{th} and 11^{th} centuries and the 40-odd Iranian astrolabes from the 12^{th} to the 16^{th} century. The potential of the sources from Rasulid Yemen and Mamluk Syria and Egypt is illustrated by the few presented in this volume (**XIVa-c**). In general, my photographic archives for later Islamic astrolabes and medieval European astrolabes are inadequate.

Astrolabes with more than one layer of inscriptions and also instruments made up of components of different provenance are of particular historical interest. They then resemble manuscripts made up of texts by different copyists or texts with marginalia, and present an added challenge to the historian. In this study, I deliberately use such astrolabes as examples.

3 On describing astrolabes

> "Lorsque je fus bien décidé à étudier la composition et les tables de l'astrolabe de notre observatoire, je commençai par rechercher avec un soin minutieux ... ; je me mis à compter les nombres de divisions ... ; j'employai la loupe ... . Je continuai ces observations jusqu'à ce que je connus parfaitement tous les tracés, toutes les lignes, tous les caractères, toutes les marques distinctives qui pouvaient se trouver sur les différentes parties de notre astrolabe; mais surtout j'évitai de faire des rapprochements trop précipités qui auraient pu me donner des idées fausses et m'empêcher de bien observer ce qui ne l'était pas encore." Frédéric Sarrus, "Astrolabe marocain" (1853), p. 28. Sarrus was too modest to mention that he had also taught himself Arabic in order to publish the Strasbourg astrolabe: see Francis Debeauvais and Paul André Befort in *Strasbourg Astrolabe Catalogue*, pp. 115-118.

In the 1950s Derek J. de Solla Price and his assistants at Yale University prepared a very useful checklist of about 1100 instruments, mainly astrolabes.[29] Each piece was assigned an International Instrument Checklist (IIC) number, here preceded by the symbol #. In addition, the location, date, maker's name and size, were given, with the data arranged according to each of these criteria. Price's numbers up to 3999 have been extended up to 9999 by the present author to include all Islamic instruments and all European ones up to *ca*. 1550.

In any serious description of an astrolabe one should find basic information, including the IIC number, present location, provenance (if known), bibliography, size, followed by descriptions of the throne, mater, rete, plates, back and alidade. Significant artistic features on the throne and rete and other decoration are noted. Due attention is to be paid to numeral forms, star-names, inscriptions including maker's names, dates of construction and dedications. The recording of star-names is of prime importance, but those colleagues who cannot read the names often leave them out, simply counting them. For names of astrolabe stars in Arabic we have an important new study by Paul Kunitzsch,[30] supplementing his earlier one on astrolabe stars in Latin texts.[31] The reading of corrupt Arabic star-names in Gothic script is an exercise fraught with difficulty; they seldom correspond directly to any of the star catalogues from textual sources so diligently documented by Kunitzsch.[32] Only the strong of heart will venture to investigate the positions of the star-pointers. Also important is the density of the mathematical markings, and the way the various scales are divided. I use the notation of the form **5°/1°-10°** to denote that a given scale is divided for each 5°, with subdivisions for each 1°, and arguments are labelled for each 10°. The technological aspects of individual instruments are important, but are usually neglected, not least by this writer. Marks of construction and uncompleted instruments are particularly revealing: see **Figs. 3.1a-b**. The accuracy of the scales has rarely been investigated.[33] Likewise, study of the metallurgical content of the metal used for the instruments is still in its infancy.[34] In any case, all significant markings, even those visible only with a magnifying glass, should be recorded. Sarrus was so carried away by the Arabic inscriptions on the Strasbourg astrolabe that he neglected to mention the obscure Latin graffiti scratched on the back.[35]

Various procedures can be used to check the date of construction of an astrolabe or to date those on which no date occurs. Modern computer techniques facilitate the dating of astrolabe retes but one must be sure that the rete is not merely a copy of an earlier one.[36] Reliance on

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[29] Price *et al*., *Astrolabe Checklist*. See also Price, "Astrolabe Checklist", for the motivation.

[30] Kunitzsch, "al-Ṣūfī and the Astrolabe Stars".

[31] *Idem*, chapter "Astrolabsterne", in *Arabische Sternnamen in Europa*, pp. 59-69.

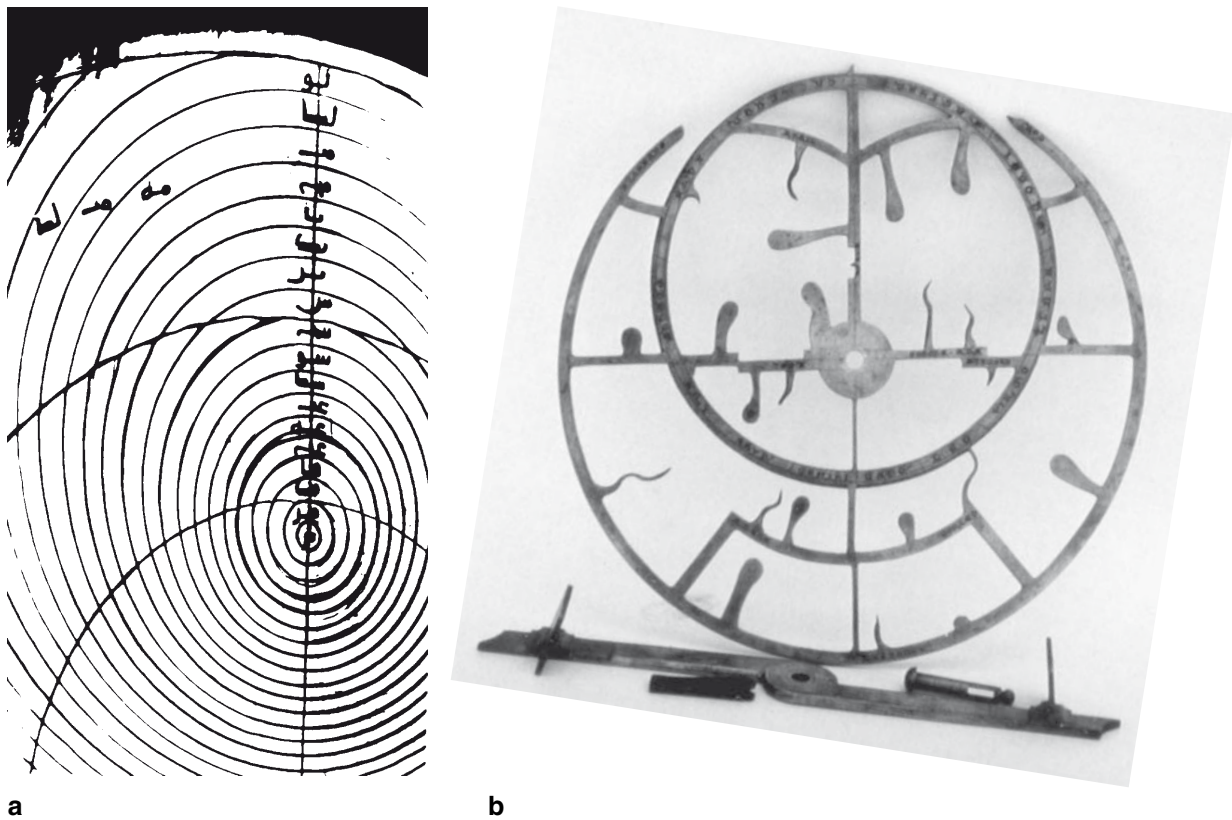
[32] See King, "Star Names on Three European Astrolabes".

[33] Studies of the accuracy of markings on (medieval and) Renaissance instruments are Chapman, "Scale Gradations"; and Gordon, "Metalworking Technology".

[34] The only serious published account of a metallographic analysis of such instruments is Gordon, "Metallography". Another that does not inspire as much confidence is Gratuze & Barrandon, "Nouvelles analyses de l'astrolabe dit 'carolingien'", not least because of the pathetic conclusion: "l'astrolab (dit 'carolingien') ... n'est pas une contrefaçon récente".

[35] These are appropriately featured in *Strasbourg Astrolabe Catalogue*, pp. 68-69.

[36] New techniques and insights are provided in Stautz, *Mathematisch-astronomische Darstellungen auf*

a b

Figs. 3.1a-b: (a) These construction marks on a plate of the astrolabe of al-Sahl al-Nīsābūrī (#137—see **XIVb-2**) help to reveal the way in which the altitude circles were constructed. However, the maker mislabelled the circles on the upper left, so that they do not correspond to the correct labelling on the vertical axis. [Photo by the author, courtesy of the Germanisches Nationalmuseum. Nuremberg.]
(b) A medieval French astrolabe with a rete on which the cutting of the star-pointers has not been completed (#4551). [Object preserved at the Osservatorio Astronomico di Roma; photo by Dr. Silke Ackermann, then of Frankfurt.]

the calendrical scales for dating purposes is less well-advised, for here, at least in medieval Europe, apparently blind tradition prevailed.[37] The style of the engraving, and above all, the various features of each particular instrument, constitute more reliable criteria. Even the shape of the throne of an astrolabe or the format of the equinoctial bar on the rete can be important for classifying, and hence even dating, an instrument.

Good photographic documentation is essential. It is important to display the front and the back without any radial rule on the front, and without the alidade on the back. It is difficult

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mittelaterlichen Instrumenten. In *idem*, "Astrolab aus dem Jahr 1420", dealing with the Italian astrolabe #4523, Stautz shows how the maker confused ecliptic and equatorial coordinates. Other important studies are Kunitzsch & Dekker, "The Stars on the Carolingian Astrolabe", and Dekker, "Astrolabe Stars".

[37] On this subject, see Poulle, "Peut-on dater les astrolabes?", and more recently, G. Turner, "Dating Astrolabes".

to persuade museums and auction houses to refrain from illustrating the alidade on the front or obscuring inscriptions on the back—**Figs. 3.2a-c—**but this is an old habit that dies hard.[38] The alidade and any radial rule can be illustrated alongside the back of or the front af an astrolabe, but only if it certain that they are original (and often they are not). Photos all all of the plates should be prepared, front and back on separate shots; this serves for basic documentation. However, some plates may be of particular historical interest and should be illustrated separately. Close-up details of this or that inscription or astronomical marking or technical defect can often be as important as the basic photos of the front and back of an astrolabe.[39]

It is important to note that it is the markings on the metal surface that are of interest, not the metal itself. Most of the photos in my collection show obscure markings on very grey metal surfaces, and those included in this volume are mainly exceptions to this general rule. Only a few museums can make decent photos: the Museo di Storia della Scienza in Florence, the Benaki Museum in Athens, the Adler Planetarium in Chicago, ... , also Christie's of London; the list is short. (I identify these because they did not even charge for their excellent photos.) Some major museums seem incapable of making decent photos of instruments: I shall not name them even though I have paid them dearly for their lousy photos. The author must control the relative size of the illustrations; a publisher interested in art history and pretty things once published a photo of mine of the wedge of an astrolabe as large as the astrolabe itself, simply because the pin is in the shape of a very pretty horse's head. Of course, modern technology has overtaken me, but it is not insignificant that some of the best of the available photos of astrolabes are old-style black-and-whites, and I have yet to see a usable set prepared with a digital camera.

Only when an astrolabe has been described in detail together with appropriate illustrations can it be regarded as "published". In some cases, it is worthwhile to compare the piece with other related ones. And this is the problem: some astrolabes are worth a book each,[40] for others a description of a few pages will suffice, and for a few, the briefest description together with references to other published instruments are adequate. In some rare cases, local scholars have published cohesive accounts of all the astrolabes, sometimes both Islamic and European, in one location.[41] And for many astrolabes, the available photographic documentation is inadequate.

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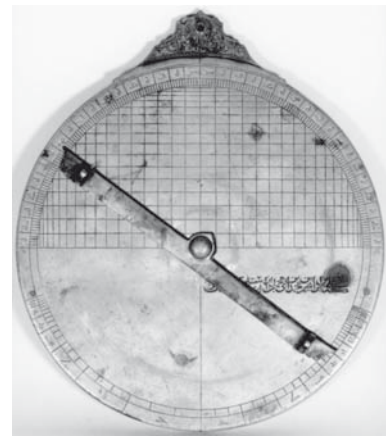
[38] A Sotheby's catalogue of 2004 shows an alidade obscuring some of the star-names on the front of a previously-undocumented astrolabe by Maḥmūd, the son of Jalāl (**XIVd**).

[39] Another of 21.09.2000 shows all details of all parts of a Safavid astrolabe (lot 27) except the back, on which there is an inscription of prime importance for the history of Safavid instrumentation. According to Sotheby's no photo of the back was prepared, yet the maker's name was read as Muḥammad Ḥusayn ibn Muḥammad Bāqir al-Yazdī and the date as 1058 H [= 1647/48]. This inscription could have been compared with that of the elusive "Muḥammad Ḥusayn" who signed one of the three known Safavid Mecca-centred world-maps. See King, *Mecca-Centred World-Maps*, pp. 255-256, and now the addenda to vol. 1, section **VIIc**, at the end of this volume.

[40] This is certainly the case for the universal astrolabe of Ibn al-Sarrāj: see Charette & King, forthcoming.

[41] I think of van Gent, *Leiden MB Astrolabes*; Stautz, *Munich Astrolabes*; and Debeauvais & Befort, *Strasbourg Astrolabes*.

Figs. 3.2a-c: Please don't do this! (a): A monumental early-13th-century astrolabe made for the ruler of Syria, rendered absurd by someone having put the rete on the back. This is particularly sad, because it is the only high-quality photo of the instrument that has ever been made. (b): An astrolabe made by a Yemeni sultan in the late 13th century, here shown with the alidade on the front in order to obscure the rete. (c): Here, the signature of the leading astronomer of the 14th century—the man who developed Copernicus' solar, lunar and planetary models 150 years before Copernicus—is cunningly obscured by an alidade. [Credits withheld in deference to the responsible authorities.] See also **Figs. XIIa-12e**, **XIIIc-2**, **XIVb-7c** and **7*a**, and **XV-19** for outrages of the same kind committed against medieval European astrolabes.

Whilst these astrolabes can reveal a host of technical and decorative details, thye are generally silent about what would be of greatest historical interest for us: how and where they were made; how and by whom and for what purpose they were used; and how they came to be in their former or present locations. Take the fine Kuwait astrolabe of Nasṭūlus (**XIIIc-3.1**) and the magnificent astrolabe of al-Khujandī (**XIIIc-9**): how long did they remain in Baghdad and what happened to them thereafter? Or the astrolabes of the Yemeni sultan al-Ashraf (**XIVa**): how long, if at all, was the New York example in the possession of a succession of Yemeni sultans, and what happended to his other astrolabes? Or the 1062 Byzantine astrolabe now in Brescia (**4**): was it part of some Crusader's booty after the massacre in Constantinople? Was it brought to Italy by Cardinal Bessarion? Or the 10th-century Latin astrolabe from Catalonia (**9**): where was it before it resurfaced in the 1950s? Or the 14th-century Picard astrolabe with monastic ciphers (**10.3**): was it made in a monastery in Picardy and how did it end up in the possession of a monk from Liège in the early 16th century? I have attempted some kind of reconstruction of the early fate of the 14th-century Spanish astrolabe with engraving in Hebrew, Latin and Arabic (see **XV**). However, such enterprises are fraught with difficulty and very prone to generate misinterpretations. It is rare indeed that we have an account of a medieval astronomer actually using an instrument that we can (almost) identify with a surviving piece; such is the case with the remains of two astrolabes by Ḥāmid ibn ʿAlī that were made in Baghdad, one of which was made for an Egyptian but ended up in Sicily, and the other of which ended up

in Mamluk Cairo: one such, according to his own testimonial, was used by the celebrated astronomer Ibn Yūnus *ca*. 990 (see **XIIIa-8**).

4 The form of Greek astrolabes and the only surviving astrolabe with inscriptions in Greek

The early history of the astrolabe is obscure. The astrolabe as it was known in medieval times was probably first described by Theon of Alexandria (*ca*. 375 C.E.). Since no astrolabes survive from Antiquity, we have to rely mainly on textual sources for the early history of the instrument.[42] A single astrolabe with Greek inscription survives, and this together with the earliest surviving Islamic astrolabe from the late 8th century, whose rete is in the same tradition, enables us to reconstruct the form in which the basic astrolabe was transmitted.[43] No astrolabes are known from before about 750, and so the form in which the instrument was transmitted to the Muslims in the 8th century has to be deduced from 7th-century treatises in Greek and Syriac. But clearly, already at that time, the astrolabe possessed all of the basic features that characterised it for the next millennium.

Philoponus (*ca*. 625) mentions a rete with an ecliptic and pointers for 17 or more stars that could rotate over any one of a set of seven sets of latitude-dependent markings for each of the climates of classical geography.[44] With such a series of plates serving the entire inhabited world, the instrument could be considered "universal". These plates were marked with the projections of the celestial equator and the solstitial circles, as well as with the curves for the seasonal hours. The altitude circles marked on these plates might be for each 6°, 3° or 1° of celestial altitude, depending usually on the size of the instrument. The back of the astrolabe was essentially empty but for a scale which served to measure celestial altitudes by means of the alidade.

An instrument of great historical interest is the Byzantine astrolabe made by Sergios "the Persian" in 1062 preserved at Brescia (#2): see **Figs. 4.1a-b**.[45] This is more developed than the basic instrument described by, say, Philoponus. It is also larger than most early astrolabes, with a diameter of 37.5 cm. The inscriptions are in Greek and all numbers are in Greek alphanumerical notation.[46] The throne is ornate and in a style quite different from contemporaneous Islamic instruments. The rete is rather simple and bears only 14 star-pointers. The representation of Vega (ΛΥΡΑ = *al-nasr al-wāqiʿ*) as a bird is also attested on the very early Baghdad astrolabe mentioned below (**5** and **XIIIb**). The three surfaces of the mater and single plate are rather sophisticated in that they have altitude circles for each 6°, but for each 3°

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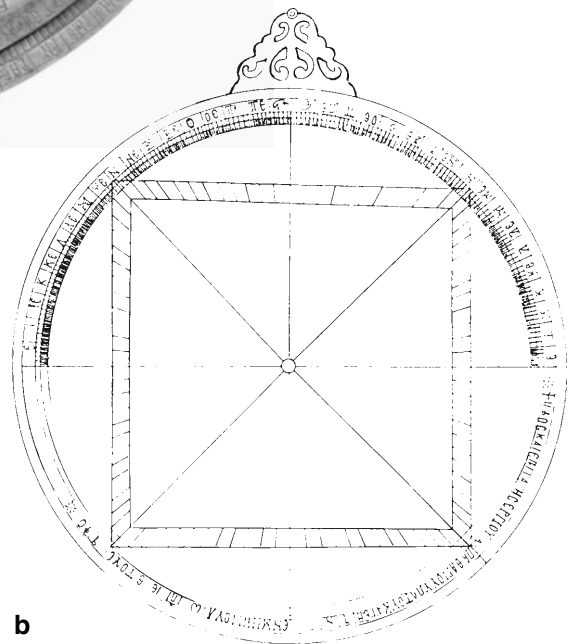
[42] See Neugebauer, *HAMA*, II, pp. 868-879, and also *idem*, "The Early History of the Astrolabe".

[43] See Stautz, "Die früheste Formgebung der Astrolabien", for a comparison of these two pieces.

[44] There is an English translation in Gunther, *Astrolabes*, I, pp. 61-81. I could not find my copy of Segonds, *Philopon sur l'astrolabe*, when I needed it (Jan., 2005). See further **XIIa-9**.

[45] This piece was published in Dalton, "Byzantine Astrolabe" (1926), summarized in Gunther, *Astrolabes*, I, pp. 104-108 (no. 2). It was presented to the museum in Brescia by Francesco Salier in 1844. This piece was probably brought to Italy from Constantinople by Bessarion. It was available to Regiomontanus *ca*. 1460: see **Fig. 10.6b**.

[46] On this notation see, for example, Aaboe, *Episodes*, A, pp. 103-104, and Ifrah, *Histoire universelle des chiffres*, 2nd edn., I, pp. 529-540, and King, *The Ciphers of the Monks*, pp. 290-294, and the other references there cited.

Figs. 4.1a-b: (a) The front of the sole surviving astrolabe with inscriptions in Greek. Note that the plate is not properly secured so that its meridian is not in line with the vertial axis of the mater. Note also that the altitude circles have been made denser between the solstices. For an illustration of one of the plates see **Fig. XVI-3.1**. [Courtesy of the Museo dell'Età Cristiana, Brescia.]
(b) This lithograph by O. M. Dalton (1926) gives a better impression of the back of the Brescia astrolabe than any modern photos. [From Gunther, *Astrolabes*, I, p. 106, after Dalton, "Byzantine Astrolabe".]

between the solstices for improved operations with the sun. These astrolabic markings serve the 4th climate (Rhodes at latitude 36°), and the 5th (Hellespont at 40° and Byzantium at 41°): see **Fig. XVI-3.1**. On the back of the Brescia astrolabe is the quadruple shadow-square mentioned above, based on a gnomon length of 12 digits in the Indian/Islamic/Byzantine tradition (but from the Islamic, not the ancient Greek tradition!). This is a later addition, not least because it interferes with the inscription around the rim. Otherwise, the inscriptions and star-names are fully Greek with no trace of Islamic influence.

5 The earliest Islamic astrolabes

The oldest surviving Islamic astrolabe is preserved (appropriately) in the Archaeological Museum, Baghdad. It has a rete with 17 stars, plates for each of the climates, and no markings on the back beyond an altitude scale.[47] The star-positions are Ptolemaic, adjusted for *ca*. 750 with Ptolemy's inaccurate value of precession (so that they actually correspond to a date a couple of centuries earlier!). All numbers are now in the Arabic alphanumerical (*abjad*) notation.[48]

In addition, there are a good dozen other astrolabes extant from the period 900-1000, all of which happen to be of *Eastern* Islamic provenance, all of the earliest ones from Baghdad,[49] then a few from Isfahan.[50] The most sophisticated of these Baghdad astrolabes, displaying numerous novel features, were constructed by two 10th-century astronomers, Ḥāmid ibn ʿAlī al-Wāsiṭī and Ḥāmid ibn Khiḍr al-Khujandī. Then there are another dozen astrolabes that survive from the following century, virtually all of which just happen to be of *Western* Islamic provenance.[51]

Of the numerous treatises on the construction and use of the astrolabe from the period 800-1100, the various texts by al-Khwārizmī (*ca*. 825), Ḥabash and al-Farghānī (*ca*. 850), al-Sijzī (*ca*. 950), and al-Bīrūnī (*ca*. 1025), almost all still available only in manuscript form, are the most useful for our present purposes in that they document most of the innovations.[52] All of these new features are Eastern Islamic in origin, although some appear only on the few Western Islamic instruments that have been preserved for us.

Within two centuries of the adoption of the astrolabe, Muslim astronomers had devised a palette of additional features, some of considerable mathematical sophistication. Some of these are attested only on late Indo-Persian instruments, but there are few unusual features on these that are not of much earlier origin.

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[47] On this see now **XIIIb**.

[48] See, in addition to the article "Abdjad" in *EI*$_2$, Destombes, "Chiffres coufiques", Irani, "Arabic Numeral Forms", and King, *The Ciphers of the Monks*, pp. 295-302. On alphanumerical numeral notation in medieval Europe see *ibid*., pp. 290-308, and also the text to n. 70 below.

[49] See now **XIIIc**.

[50] See now **XIIIc-A** and **B**.

[51] For three of these see Woepcke, "Arabisches Astrolabium" (1855), King, "Nürnberger Astrolabien" (1992), pp. 568-570 (no. 1.70); and Maier, "Astrolab aus Córdoba" (1999).

[52] Richard Lorch is preparing for publication the treatises of al-Farghānī and al-Sijzī. For the treatise of al-Khwārizmī see Charette & Schmidl, "al-Khwārizmī on the Astrolabe". The treatise on al-Bīrūnī desrves similar treatment.

a

b
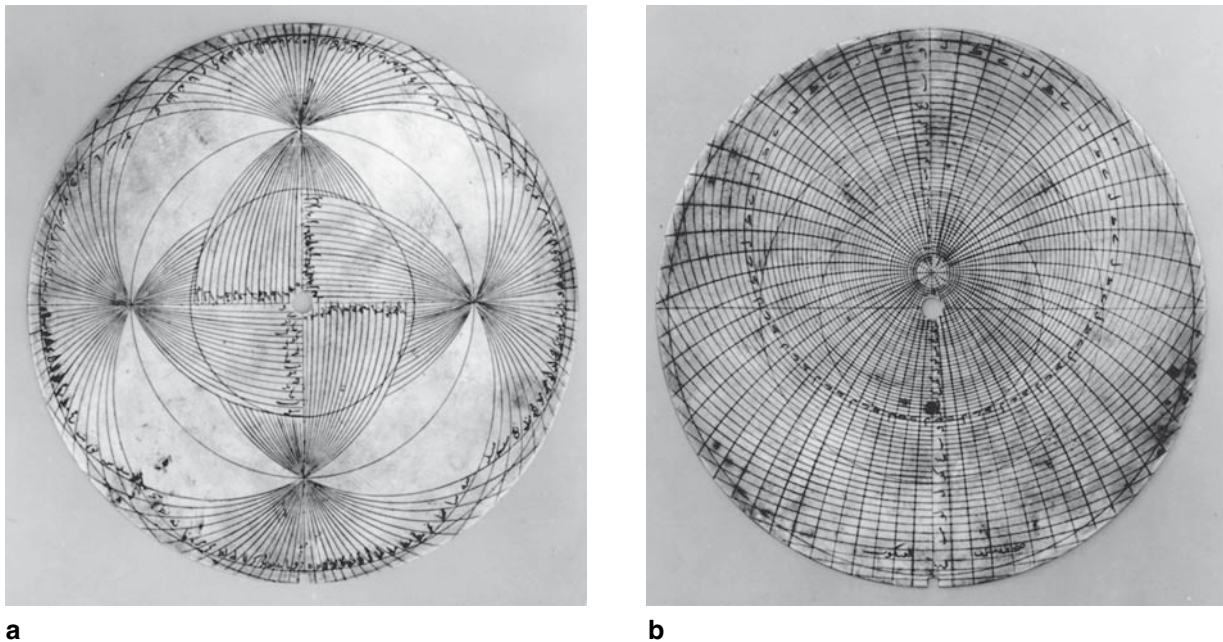
Fig. 5.1a-b: A pair of plates from an astrolabe (#3550) by Muḥammad Zamān of Meshed, dated 1062 H [= 1651/52], serving four sets of half-horizons (a) and the Arctic Circle (b). The latter is appropriately labelled *ṣafīḥat mīzān al-ʿankabūt*, which means "plate for checking the accuracy of the ecliptic ring on the rete". Muslim astrolabists had been making plates of this kind since the 9th century. See **Fig. 10.9a** for the front of this astrolabe. [Courtesy of The Metropolitan Museum of Art, New York.]

Amongst the features added to the basic astrolabe before the end of the 10th century are:

(1) Curves for the azimuth (first mentioned by al-Khwārizmī);

(2) Curves for twilight and the daylight prayers on plates for a specific latitude (mentioned by al-Bīrūnī);

(3) A plate displaying horizons for a series of latitudes, for all operations involving only horizons and meridians, and extending the use of the instrument beyond the latitudes served by the regular plates (introduced by Ḥabash);[53]

(4) A plate for the latitude of the Arctic Circle, serving conversion of equatorial and ecliptic co-ordinates (found on the astrolabe of al-Khujandī);

(5) Plates for latitudes 0° and 90° (found on the astrolabe of al-Khujandī), and also 72° (found on some 11th-century Andalusī astrolabes) and 16;30° *south* (found on one 11th-century Andalusī astrolabe), serving pedagogical purposes;

(6) Astrolabes with an extended radius of projection, called *kāmil*, "complete", (attested already in the 10th century);

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[53] Since the horizon on an astrolabe is symmetrical with respect to the vertical meridian, half of the horizon will suffice for such purposes. Usually four sets of different batches of half-horizons are represented, the latitudes so chosen as to give maximum coverage for all latitudes from a few degrees to the Arctic Circle and sometimes even beyond. See, for example, **Fig. XIVd-1.5**.

(7) Elaborate combinations of the astrolabic markings on plates to produce, for example, designs called ogival, "like a Gothic arch", essentially to challenge the wits of the user, but also sometimes to represent two sets of markings for different latitudes on the same plate (attested already in the 10th century);
(8) Plates for the astrological operation known as "casting the rays", for a specific latitude (again mentioned by al-Bīrūnī);
(9) The scales for the shadows (first mentioned by al-Khwārizmī), be they circular (on the rim), linear (within one of the lower quarters of the back), or in the form of the shadow-square that later became standard;
(10) Horary quadrants for finding the hour of day are now known to date from the 9th century (anonymous Baghdad astronomers). They were of two kinds: universal, yielding the time approximately for any latitude and based on a simple approximate formula, and specific, serving a single latitude.
(11) The sine quadrant (probably due to al-Khwārizmī) was originally devised for time-reckoning using the same simple approximate formula that works for all latitudes, but the derivatives so popular in later centuries could be used for finding numerical solutions to any of the standard problems of spherical astronomy. (See below for more on quadrants.)
(12) Special graphs were introduced to display the duration of twilight or the astronomically-defined altitude of the sun at the afternoon prayer, both as a function of solar longitude for a specific latitude.
(13) Non-uniform graduated scales were conceived to display certain astronomical functions such as the solar declination as a function of solar longitude or the altitude of the sun at the afternoon prayer as a function of the solar meridian altitude.

Attested in the first centuries of Muslim involvement with the astrolabe (al-Bīrūnī describes both) are:
(14) The markings for the seasonal hours on the alidade (based on a very crude approximate formula for time as a function of solar altitude, and attributed to Nasṭūlus); and
(15) The viewing tube on the alidade.

Appearing for the first time on these early instruments we find:
(16) Geographical gazetteers (such as that on the Cairo astrolabe of Nasṭūlus); and
(17) Lists of astrological data (such as on the astrolabes of al-Wāsiṭī and al-Khujandī, planetary symbols are used to render the data more compact);
(18) The qiblas of various cities might also be displayed graphically (the earliest are on an 11th-century astrolabe from Isfahan). Graphical representations of the solar altitude in the azimuth of the qibla appear to be a later addition (common in Iran from the 17th century onwards).
(19) The calendrical and solar scales for finding the longitude of the sun at any time of the year, which became standard on *Western* Islamic astrolabes, are—unlike all of the above—*Western* Islamic innovations.[54]

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[54] The historical development of such scales merits a detailed investigation; scholars are usually too concerned

It is not at all clear how early instruments were made bearing world-maps, standard or Mecca-centred. We only have two examples of such maps on late astrolabes, and it would not surprise me if it could be shown that earlier astrolabes were made with such maps:

(20) On a 17th-century astrolabe from Lahore (#4143) we find a schematic world-map with correctly executed longitude and latitude scales, and on an early-19th-century Iranian astrolabe (#58) we find a plate with a grid for a world-map centred on Mecca, on which no localities have been inserted.[55]

Then there are features mentioned in texts that are, alas, not attested on any surviving instruments. Of these we mention only:

(21) The transversal scale (described by al-Sijzī, and later by Levi ben Gerson), and

(22) Solar-lunar scales for calculating moonrise and moonset (described in treatise associated with al-Khwārizmī).

Finally, we should mention:

(23) monumental astrolabic clocks of which several are known to have been made in the Islamic Middle Ages and one survives in Fez (see **X-5.4**).

What else can one possibly add to a standard astrolabe to make it more useful? The list continues below with innovations of a different kind. As we shall see, medieval European astrolabes tended to be restricted to the standard variety.

Early Muslim astrolabists had differing opinions regarding which sets of stars should be represented on the rete. In his book on the constellations, ʿAbd al-Raḥmān al-Ṣūfī mentions 44 astrolabe stars,[56] but he is silent on the different traditions. These should be investigated in the light of contemporaneous star catalogues, found in the astronomical handbooks known as *zijes*[57] as well as in astrolabe treatises. Hoever, the stars found on the retes of surviving astrolabes present a quite different picture.

The choice of the latitudes underlying the plates was generally influenced by the preoccupation with the geographical climates of Antiquity; the standard practice of recording the maximum length of daylight along with the latitude served by the plate is to be regarded as a survival of this association. Underlying these lengths on virtually all of the earliest astrolabes, and indeed on most later ones too, is the Ptolemaic value of the obliquity of the ecliptic (in spite of the fact that much better values had been determined by Muslim astronomers in the 9th century). The function of the gazetteer was originally to enable the user to determine which plate would best serve a particular locality (the earliest example lists only latitudes). When place-names were introduced on plates it was understood that these localities were best served by that particular plate, not that the localities all had the latitude indicated on the plate.

Muslim astronomers made substantial contributions to the construction of the astrolabe. In

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to show that some scales on medieval European astrolabes are unreliable. See the references in n. 37 above.

[55] Both are illustrated in King, *Mecca-Centred World-Maps*, pp. 95-97.

[56] See n. 30 above.

[57] On star-catalogues in the Islamic sources see Kunitzsch, "Medieval Star Catalogues", and King & Samsó, "Islamic Astronomical Handbooks and Tables", pp. 27-28.

the early 9th century al-Khwārizmī introduced a handy trigonometric function with which the calculation of the radii and centre-positions of the various circles on a typical astrolabe is greatly facilitated.[58] His late contemporary, al-Farghānī, used this auxiliary function to generate tables displaying the size and positions of the circles of altitude and azimuth for each degree of argument, for each degree of terrestrial latitude from 15° to 50°. These tables, containing about 14,000 entries, and their derivatives were widely used in astrolabe construction in the Islamic world for centuries, but they were unknown in Europe until the 1970s.[59] (The underlying theory is, of course, precisely that proposed by Henri Michel in his *Traité de l'astrolabe* in 1947.[60])

6 Some Islamic astrolabes

As an example of a *typical* Islamic astrolabe let us consider the undated piece by Muḥammad ibn Ḥāmid (ibn Maḥmūd) al-Iṣfahānī (#3532) now in a private collection in London, having been purchased from Alain Brieux in Paris. It has not been published, although illustrations of the front and back appeared in a 1989 catalogue.[61] The maker is known from three other pieces dated between 556 and 571 H [= 1161-76] (the first of these is illustrated in **Fig. X-4.1.1**, and the last is described in **XIIIc-B1**), and it is clear that he was operating in Isfahan. See **Figs. 6.1a-b**.

The original inscriptions are in a legible *kūfī* script. The throne is more developed than those on the earliest Baghdad astrolabes, and has pronounced lobes and three holes. The rete is also slightly more developed than the earliest known ones, but in the same basic style. There are a few more stars (actually 32, including the very unusual *ʿātiq al-thurayyā*, which is not even in al-Ṣūfī's list of astrolabe-stars),[62] so that, for example, both hands and both legs of Orion are indicated. Two stars on the lower left and right have pointers stretching across the lower equinoctial bar, and another pointer on the lower right starts on that bar and stretches across to the outer circumferential frame. It was to avoid such rather awkward situations that later astrolabists introduced more complicated rete frames.

There is a problem with the plates: when I inspected the piece in London in 1990 there were none, but a 1990 photo shows a plate for 30°. The mater bears astrolabic markings for latitude 36°, including altitude circles for each 6° and no azimuth circles. The plates would have fitted onto a peg protruding from near the bottom of the mater that is visible beneath the rete.

The back bears a double shadow-square for 6;30 feet on the left and 12 digits on the right, as well as scales to the same bases on the outer rim. In the upper left quadrant there are graphical representations of the altitude of the sun at the beginnings of the *ẓuhr* and the *ʿaṣr*, both for latitude 32°, which serves Isfahan. The longitude of the sun is represented both on the vertical and horizontal radii, the appropriate zodiacal signs being represented by numbers. The curves

[58] **VIa-9**.
[59] **VIb-7** and **16**, and also King, "Yemeni Astrolabe", pp. 107-111, now in **XIVa-3**.
[60] Michel, *Traité de l'astrolabe*, pp. 62-63.
[61] *Riyadh/Washington 1989 Catalogue*, p. 5.
[62] On this star see Kunitzsch, *Arabische Sternnamen in Europa*, p. 144 (no. 63).

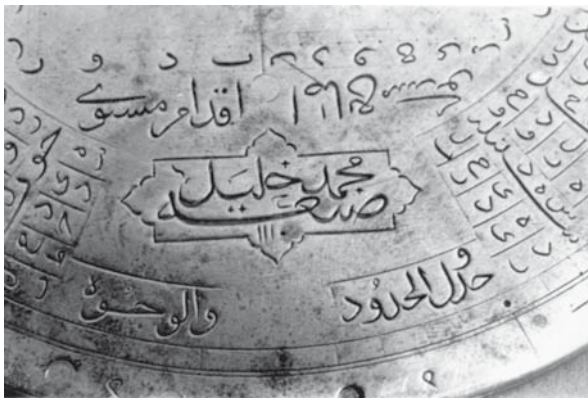
Figs. 6.1a-d: (a-b) The front and the back of the undated astrolabe of Muḥammad ibn Ḥāmid al-Iṣfahānī (#3532), made in Isfahan *ca*. 1165, showing a few modifications to the basic astrolabe inherited by the Muslims from the Greeks. (c) The mater showing astrolabic markings for latitude 36°. (d) The maker's signature. [Photos courtesy of the late Alain Brieux, Paris.]

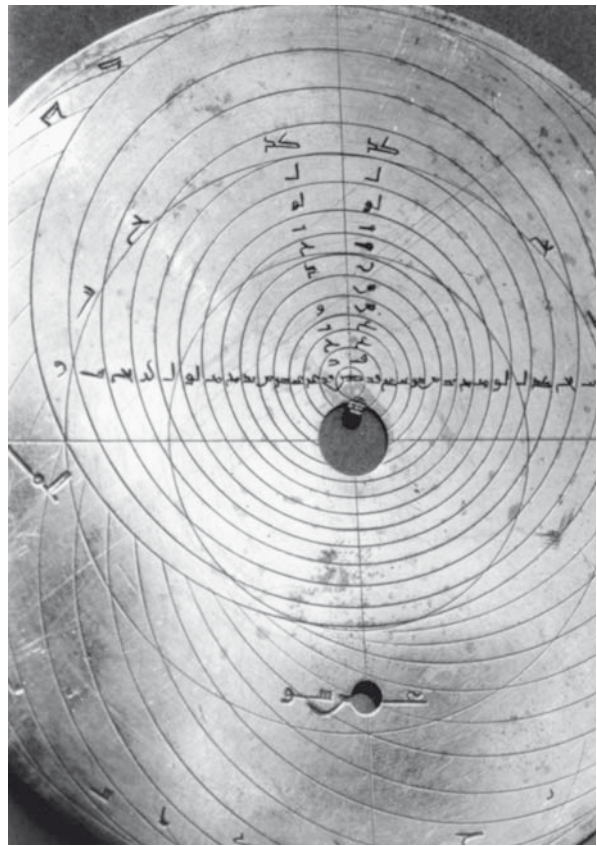
a

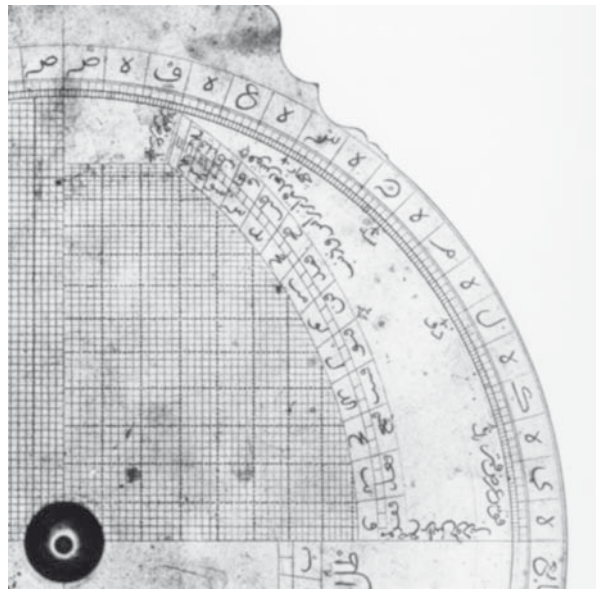
b

c

Figs. 6.2a-g: An astrolabe from the late 12th century reworked in the 17th (#3922). [Photos for a-g by the author, courtesy of the Institut für Geschichte der Naturwissenschaften, Frankfurt.]

(a) The front.
(b) The back.
(c) The original signature on the back of the throne.
(d) The later signature of Muḥammad Khalīl.
(e) A detail of one of the original plates, serving latitude 66°.
(f) A detail of the later plate for Shiraz.
(g) The most interesting technical feature on the back: a scale for determining the lunar latitude.
(h) A similar feature on an undated astrolabe by ʿAbd al-Aʾimma (#38), already noted in Gunther, *Astrolabes*, I, p. 153. See also *Oxford Billmeir Supplement Catalogue*, p. 27 (no. 169) and pl. XXIIc for a third example. [Courtesy of the Museum of the History of Science, Oxford.]

d

e

f

g

h

have been drawn so as to connect a series of points corresponding to the altitudes for the signs, the values probably having been taken from a table in a manual for astrolabe construction (no such tables are known, but many manuals survive and remain to be studied). In the upper right quadrant there are indicators of the qiblas in seven cities from Baghdad (at 13° E. of S.) to Kirman (at 58° E. of S.).[63] There is a later inscription in *naskhī* script beginning (I think) on the back of the throne and ending on the front. It may be that the owner was Sulṭān Iskandar (starting the inscription on the back), who had trust in (*al-wāthiq bi-*) the greatest king (*al-malik al-akbar*), namely, God.[64] There was a potential Sulṭān Iskandar, usually called Iskandar Sulṭān (ibn ʿUmar Shaykh), who sponsored the preparation of a scientific encyclopaedia in Isfahan *ca*. 1415.[65] Otherwise there was a (*malik*, "king", rather than *sulṭān*) Iskandar ibn Kayūmarth who ruled the Caspian regions of Northern Iran in the mid 15th century.[66] In other words, the mystery of this apparently simple inscription has not been fully solved.

For other examples of Islamic astrolabes, given the fact that many are featured elsewhere in this volume, I shall restrict attention here to two pieces each with two layers of inscriptions. They both belong to the Institute of the History of Science at Frankfurt University, having been acquired from an Iranian vendor in 1960, the first for a pittance, the second for a substantial sum.

The first piece (#3922), with a modest diameter of 12.6 cm, is signed by the well-known Isfahan astrolabist Muḥammad Khalīl in 1110 H [= 1698/99], but various features (particularly the throne and the *kūfī* inscriptions all over) reveal that it was reworked from an earlier piece: see **Figs. 6.2a-g**. An original inscription by the original maker is still visible and partly legible on the throne. It reads: " ... Muḥammad ibn Aḥmad ibn ʿAlī ibn Muḥammad in the year 588 H [= 1182/83]", so that we are dealing with a reworking of *one of the oldest surviving astrolabes*.[67] Five of the plates are original, and serve latitudes 30°, 32°, 33°, 34°, 35°, 36°, 37° and 38°, as well as 66°, the Arctic Circle, and a set of horizons. The rete and part of the back, as well as one plate, with one side inevitably serving latitudes 29;30° and 32° for Shiraz and Isfahan, which no longer fits properly when the other five are installed, are by Muḥammad Khalīl.

The second Frankfurt astrolabe (#3923) is a more imposing piece with a diameter of 30.6 cm, and it bears the name of the celebrated 13th-century Iranian polymath Naṣīr al-Dīn al-Ṭūsī: see **Figs. 6.3a-d**. It is signed by ʿAbd al-Qādir Muḥibb, known by two other pieces in private collections in London and Paris, and is datable *ca*. 1620.[68] It is a typical Indo-Persian production, competently made with an elegant rete and also displaying some originality. The inscriptions mentioning al-Ṭūsī were added by a modern faker, probably to increase the price that could be sought from an unsuspecting buyer. On fakes see further **X-11** and **XIVf-7**.

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[63] Compare King, *Mecca-Centred World-Maps*, pp. 104-105.

[64] Compare the inscription discussed in King, "Medieval Spanish Astrolabe with Inscriptions in Latin, Hebrew and Arabic", pp. 33-34 and 104-106, now in **XV-2.4** and **4.4**.

[65] See, for example, *ibid*., pp. 143-145.

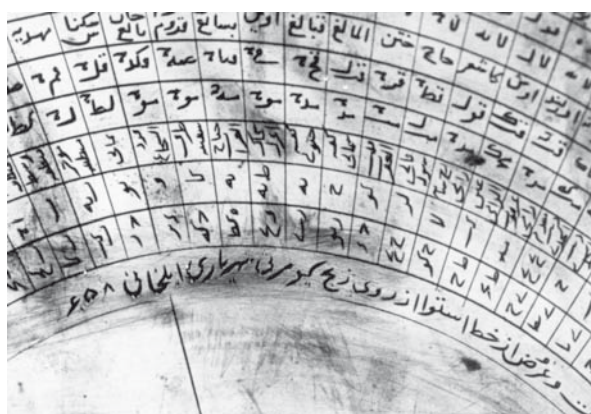
[66] Bosworth, *Islamic Dynasties*, p. 201. He was already proposed in *Riyadh/Washington 1989 Catalogue*, p. 5.

[67] This instrument is described in detail in Ackermann, "Umarbeitung eines Astrolabs".

[68] See the detailed description in Schmidl, "Ein Astrolab aus dem 17. Jahrhundert".

a

b

c

d

Figs. 6.3a-d: An Indo-Persian astrolabe from the early 17th century with 20th-century additions (#3923). [Photos by the author, courtesy of the Institut für Geschichte der Naturwissenschaften, Frankfurt.]
(a) The front showing the elegant rete.
(b) The signature of the maker.
(c) The faked reference to Naṣīr al-Dīn.
(d) The original inscription for the geographical data on the mater, showing the later faked reference to the *Īlkhānī Zīj* of al-Ṭūsī.

Interesting Islamic astrolabes keep showing up. In 2003, I saw for the first time an early-13th-century astrolabe from al-Andalus, signed by a relative of the celebrated al-Khamāʾirī, that in the same century had come into the hands of an Egyptian court astronomer (#4299). In early 2004, I noticed the curious numerical notation on a 15th-century Iranian astrolabe that had ended up in Fez (#2710), which I first thought were the enigmatic "chiffres de Fès", but which turned out to be Armenian alphanumerical notation, and I saw for the first time an early-18th-century Maghribi astrolabe marked with latitudes and longitudes of several localities between Fez and Mecca (#4300). Each of these presents a challenge: the name of the Egyptian court astronomer indicates that he worked for three successive Baḥrī Mamlūk sultans but who is otherwise unknown to us; the milieu of the Armenian who made some additions to an Iranian astrolabe that eventually landed in Fez is quite unclear; and the geographical data for the pilgrim route is different from those in the known Maghribi sources.

7 Non-standard astrolabes

Of greater scientific interest than the basic astrolabe, even when embellished with some of the novel features mentioned above, are the non-standard astrolabes mentioned in early Arabic texts. Some of these are known only by examples post-dating the end of the 11th century; for others, there are no known examples. For references the reader is referred to **X-5.2**. In this category belong:

(1) Astrolabes based on mixed north-south stereographic projections with correspondingly complex plates (still not yet properly documented in the modern literature), and known to have reached Europe from the Islamic world (see below).
(2) Astrolabes with special retes and plates on which the ecliptic and stars are superposed on the altitude circles for a specific latitude (al-Bīrūnī describes these, and some later examples survive). Another early variety that has been subject to much misinterpretation in the modern literature is a plate with celestial markings and a horizon, called *zawraqī*, that can rotate over it.
(3) Universal instruments such as the *ṣafīḥa shakkāziyya* and *ṣafīḥa zarqālliyya*, based on the universal projection (was this tradition really initiated in al-Andalus in the 11th century?), often accompanied by a trigonometric grid bearing a highly-ingenious "circle of the moon" for determining the lunar distance and thence the lunar parallax.
(4) The astrolabe with a melon-shaped ecliptic on the rete (*al-asṭurlāb al-mubaṭṭakh*), based on a non-stereographic projection (the relevant text, analysed by E. S. Kennedy, R. Lorch and P. Kunitzsch, has recently been published).
(5) "Calculating devices" for facilitating operations with the stars (devised by Ḥabash, text now published by F. Charette and P. Schmidl).
(6) Geared mechanisms for displaying the lunar phases (one example from 13th-century Isfahan but belonging to a tradition which (in Islam) goes back to at least the 10th century—al-Bīrūnī's description has been published by D. Hill).
(7) Eclipse computers (first described by Nasṭūlus—perhaps the grids for determining lunar latitude are the sole surviving parts of these?).

Fig. 7.1: The constellations of the nothern hemisphere illustrated on a plate of an astrolabe made in Isfahan *ca*. 1650 by Muḥammad Mahdī (al-Khādim) al-Yazdī (#4183). The Persian inscription translates (following Savage-Smith, "Celestial Mapping", p. 66): "Since there are discrepancies in the locations of the fixed stars amongst earlier scholars, and because the most accurate (data) are from the observations of the Franks, the locations of the fixed stars are shown here according to the authoritative observations made (by the Franks) within the past ten years." See further King, *Mecca-Centred World-Maps*, pp. 317-318 and 320. [Private collection; photo courtesy of the owner.]

(8) Astrolabes engraved with tables of the form usually found in the astronomical handbooks known as *zīj*es (devised by Abū Jaʿfar al-Khāzin in the 10th century).
(9) The universal plate devised by the late-13th-century astronomer Ibn Bāṣo, which became a popular feature in Western Islamic astrolabes.
(10) Retes bearing representations of the constellations (after *ca*. 1200) and plates bearing the same (Iran, 17th century, now after European models: see **Fig. 7.1**).

Finally, we mention:

(11) The highly ingenious linear astrolabe (no surviving examples; the available texts merit a new investigation); and
(12) the spherical astrolabe (only one complete example survives).

Recent investigations of some early European astrolabes and texts reveal that more of these types of instrument were transmitted to the West than was previously thought.

8 The quadrant in the Islamic world

Immediately related to the development of the astrolabe is the development of different kinds of quadrants, some of which were used on the backs of astrolabes. For references see **X-6**.

The universal horary quadrant, first mentioned in an anonymous 9th-century text from Baghdad and attested on various early astrolabes (often combined with a shadow-square), has already been mentioned. The fixed and movable cursors on such an instrument are described in the same text. This combination is, of course, the *quadrans vetus* of the later European sources.

The horary quadrant for a specific latitude also dates from the 9th century and soon thereafter was added to more sophisticated astrolabes in spite of the risk of compromising the "universal" qualities of the instrument.

The sine quadrant of al-Khwārizmī was invented specifically to find the time of day from the solar altitude using the same simple approximate formula which underlies the markings of the universal horary quadrant. Different varieties of sine quadrant were developed by the 10th century for the numerical solution of all the standard problems of spherical astronomy using the appropriate trigonometric formulae.

Such horary quadrants and trigonometric grids, usually incorporated on the backs of astrolabes, were popular in both East and West for many centuries. Since later astrolabes generally served a restricted range of latitudes, the inclusion of a universal horary quadrant on the back served to preserve the universal character of the original astrolabe. The quadrant functions rather well in the latitudes of the Mediterranean world, but, alas, not so well in northern European climes. Both medieval and Renaissance texts describe its *modus operandi*: it does not need a solar scale to function properly (*contra* the assertions in the modern literature).

At some time before the 12th century, apparently in Egypt, a Muslim astronomer noted that all of the operations which can be performed with an astrolabe and a single plate can also be achieved with a single half-plate, whose principal markings can conveniently be fitted on a quadrant fitted with a thread and movable bead. Thus was invented the astrolabic quadrant, different varieties of which were used in the Islamic world until the 19th century.

9 The earliest known European astrolabe

The form in which the astrolabe was transmitted to the Christian West is of considerable historical interest. Since the earliest dated European astrolabes post-date the introduction of the instrument to the West by several centuries, the textual tradition is of prime importance and has attracted the attention of a series of scholars. But also of particular interest in this regard is the so-called "astrolabe carolingien" (#3042) of the Institut du Monde Arabe in Paris: see **Figs. 9.1a-e**. This was dated to the 10th century by Marcel Destombes and is generally considered to be the earliest European astrolabe.[69] The rete is so carelessly fashioned that it must have been copied from another astrolabe or from an illustration in a manuscript. But the rete bears no resemblance to any Islamic rete. The inscriptions were added by (two different) Europeans, and the latinized Arabic alphanumerical (*abjad*) notation used to denote the latitudes is a clear indication of at least *some* Western Islamic influence; the notation was devised as an alternative to the Roman numerals at a time when the Hindu-Arabic numerals were not yet available.[70] The plates serve latitudes corresponding reasonably well to the 4th, 5th (corresponding to Barcelona, *etc*.), 6th and 7th climates, as well as the end of the 4th / beginning of the 5th (corresponding to Cordova, *etc*.), and there are more astronomical markings on the plates for [Cordova] and [Barcelona] than on the others. The inscription "Roma et Francia" was added on the plate for the 5th climate, but the other four plates were of less interest to the maker because he marked only their latitudes.[71]

Of course, any discussion of this instrument is hampered by the fact that, with very few exceptions, the earliest European astrolabes are not yet published. Not only the earliest astrolabes themselves, but also the Latin inscriptions on many of them (and also on numerous Islamic instruments which fell into the hands of Europeans who thought fit to modify them),[74] offer clues which must be taken into consideration in the evaluation of the Destombes astrolabe. The scholarly community remains divided between those who realize that this is a 10th-century astrolabe and those who think it must be a few centuries later. My attempts to propagate the former thesis, supported by the fact that the distinctive engraving corresponds to 10th-century Catalan inscriptions, and relying on comparison with several dozen other early Islamic and European instruments, have met with some success.[75] I have the feeling that the Destombes

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[69] Paris, Institut du Monde Arabe, inv. no. AI. 86-31: see Destombes, "Astrolabe carolingien"; and Stevens *et. al*., eds., *The Oldest Latin Astrolabe*, not least my contribution, listed as King, "The Oldest European Astrolabe", in which the instrument is viewed in the light of dozens of early Islamic and European instruments.

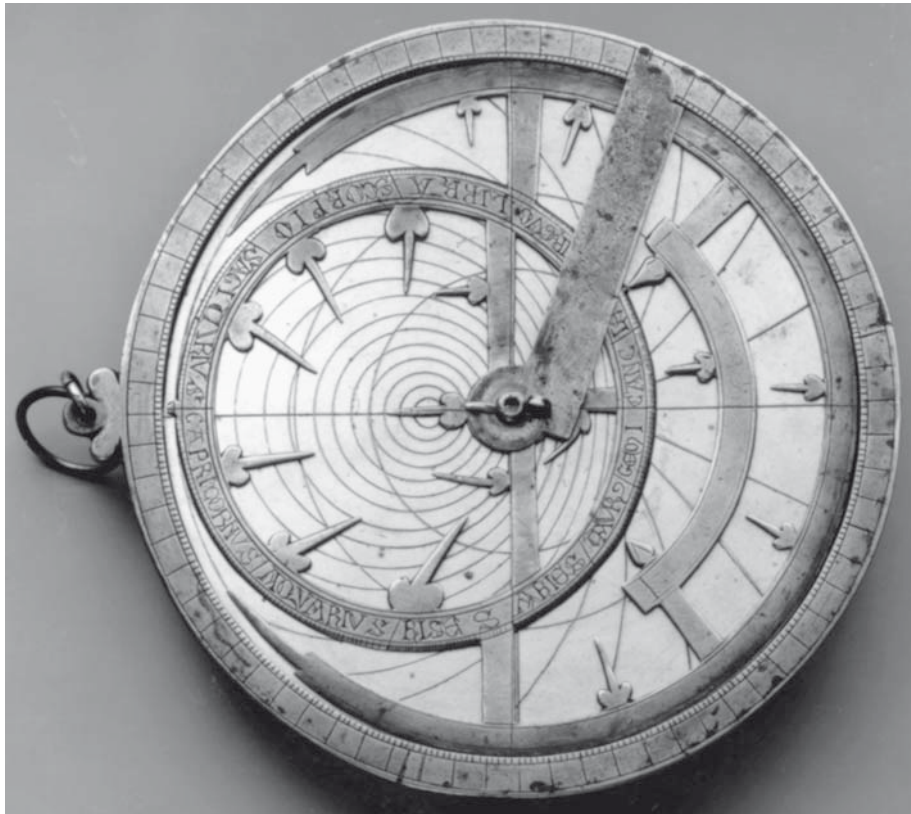
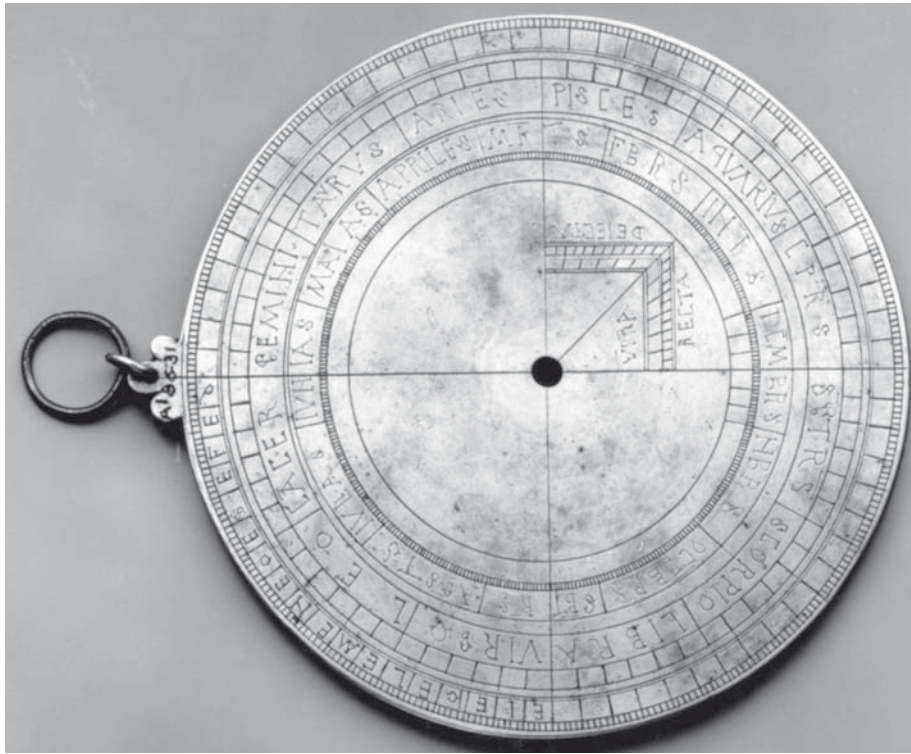
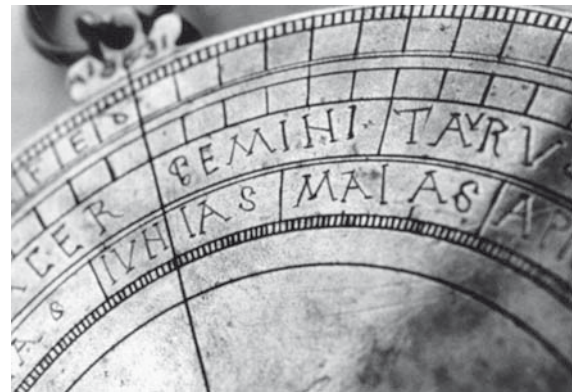
[70] On this notation see King, *The Ciphers of the Monks*, pp. 302-304.

[71] On these latitudes see also **XVI-5**, and on the problematic 47;30° see especially n. 37 to that discussion.

[72] See Mundó, "Analyse paléographique de l'astrolabe 'carolingien'".

[73] See Samsó, "*Roma et Francia* (= *Ifranja*)".

[74] See n. 83 below.

[75] On the other hand, the accumulated damage done to this piece by scholars who have no experience whatsoever of working with instruments and yet are happy to pronounce on a single piece of extraordinary complexity is well illustrated in the description in *Paris IMA 2000-01 Exhibition Catalogue*, p. 242 *ad* no. 245: here the provenance is given as "Catalogne, Italie, Sicile ou France (du Nord [!]) (?)", but at least it is acknowledged that "parfois envisagée, l'hypothèse d'un faux moderne est de moins en moins retenue". More sensible recent publications on the Destombes astrolabe, featuring it in the light of contemporaneous astrolabe texts, are Samsó, "Astrolabio Carolingio", and *idem*, "Introducción de la astronomía árabe en Cataluña", pp. 301-305.

Figs. 9.1a-b: The front and back of the oldest known European astrolabe (#3042), made in Catalonia in the 10th century. The instrument was copied not from an Islamic astrolabe, but rather from an astrolabe in a Roman tradition, not otherwise attested, with some influence from Arabic instrumentation (such as azimuth curves on some of the plates, first found in 9th-century Eastern Arabic texts). The scales on the front and most of the back have been left without numbers: the Roman numerals simply would not fit. The star-names have been omitted: the maker did not trust himself to engrave the equivalents of the Arabic names. The names of the zodiacal signs were added later, perhaps as late as the 14th century, but certainly still in Catalonia (see **Fig. 9.1e**). The distinctive forms of the engraved letters on the back are attested in other inscriptions from 10th-century Catalonia.[72] [Courtesy of the Institut du Monde Arabe, Paris.]

Figs. 9.1c-e: Details of the earliest European astrolabe. [Photos by the author, courtesy of the Institut du Monde Arabe, Paris.]

(c) Note the distinctive alphanumeric notation on the altitude scale in the upper left. The Latin forms MAIAS, IVNIAS and IVLIAS are of particular interest.

(d) The inscription "ROMA ET FRANCIA" on the plate for latitude 41;30°, written "MA L", is intended for Rome and the region of Catalunya, Francia here being derived from the Arabic *Ifranja* or *bilād al-Ifranj*, which means the lands of the "Franks", that is, the Christians bordering the Islamic part of Spain.[73]

(e) The distinctive orthography VIRGVO amongst the later engraving on the ecliptic scale of the originally unmarked rete. Needless to say, the orthography tells us something, namely, that these inscriptions were probably added in Catalonia. In the 13th century, Ramon Llull in his *Tractat d'astronomia* used the same form. See further King, "The Oldest European Astrolabe", p. 379.

astrolabe is with the sole surviving evidence of a *Roman*—I use the term loosely to denote somewhere in the Graeco-Roman world or Roman Empire—tradition of astrolabe-making, which would certainly explain why it just does not fit within the framework of what we know about Islamic and medieval European astrolabe-making.[76]

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[76] This thesis is proposed in King, "The Oldest European Astrolabe", pp. 384-385, where the paragraph beginning "An astrolabe from ca. 1300 ... ... " should be preceded by the words: "Added in proof:". A Roman connection would at least explain the presence of *Roma* on the plate for 41;30° and the curious 47;30° (see n. 71 above). A recent publication of interest is Monaco, *L'astronomia a Roma*, with a few pages devoted to Antiquity and the Middle Ages. The question whether the Romans could make scientific instruments is answered by Schaldach, *Römische Sonnenuhren*.

Finally, we mention a set of illustrations of an astrolabe with Arabic inscriptions in a 10th or 11th-century Latin manuscript (#4042, in Paris B.N.F. lat. 7412): see **Figs. 9.2a-b** and **XVI-2.2**.[77] It is an astrolabe in the tradition of 9th- and 10th-century ʿIrāqī astrolabes (see **XIIIb-c**), but clearly made in al-Andalus, probably in the 10th century. The original Arabic inscriptions are faithfully reproduced, and Latin equivalents (Latinized in the case of the star-names) are given. The rete is in the ʿIrāqī tradition, but two stars have their preferred Western Arabic names (*al-ʿabūr* and *al-ghumayṣāʾ*). The mater and three plates serve the seven climates, attested only on the very earliest surviving Eastern Islamic astrolabes (**XIIIb**). On the back there is calendrical scale, not known on any *surviving* Eastern Islamic instrument from before *ca.* 1100.[78] Otherwise, there is only a single shadow-square on the back. Even the name of the maker has been copied: Khalaf ibn Muʿādh, otherwise unknown to us. The illustrations reveal that such astrolabes were known this early in the Islamic West, and thence became available to at least one very gifted European, who could both copy the Arabic and also interpret it correctly in Latin. The Destombes astrolabe, possibly contemporaneous with this piece, is, as we have seen, in a different tradition.

10 Some other early European astrolabes

There exist close to 150 European astrolabes with inscriptions in Latin and various vernaculars (the majority) or in Hebrew (the minority), mostly unsigned and undated, which can be associated with the period between 1200 and 1500. Most of these have now been catalogued, many for the first time.

Such astrolabes generally have the Gothic forms of the Hindu-Arabic numerals.[79] However, a few early examples have no numbers at all on the scales, presumably because there was insufficient space for the Roman numerals or even the Gothic numerals, or they use Roman numerals where there *is* plenty of space, as for the latitudes on the plates.[80] Most medieval European astrolabes have star-names transliterated from the Arabic and bear other features indicating Islamic influence, although this may only be apparent if one is familiar with Islamic instrumentation. For example, the inspiration behind two of the most remarkable medieval European instruments, a French geared astrolabe from *ca*. 1300 (now in the Science Museum, London) (#198)[81] and an Italian astrolabe bearing a rete with a mixed north-south projection

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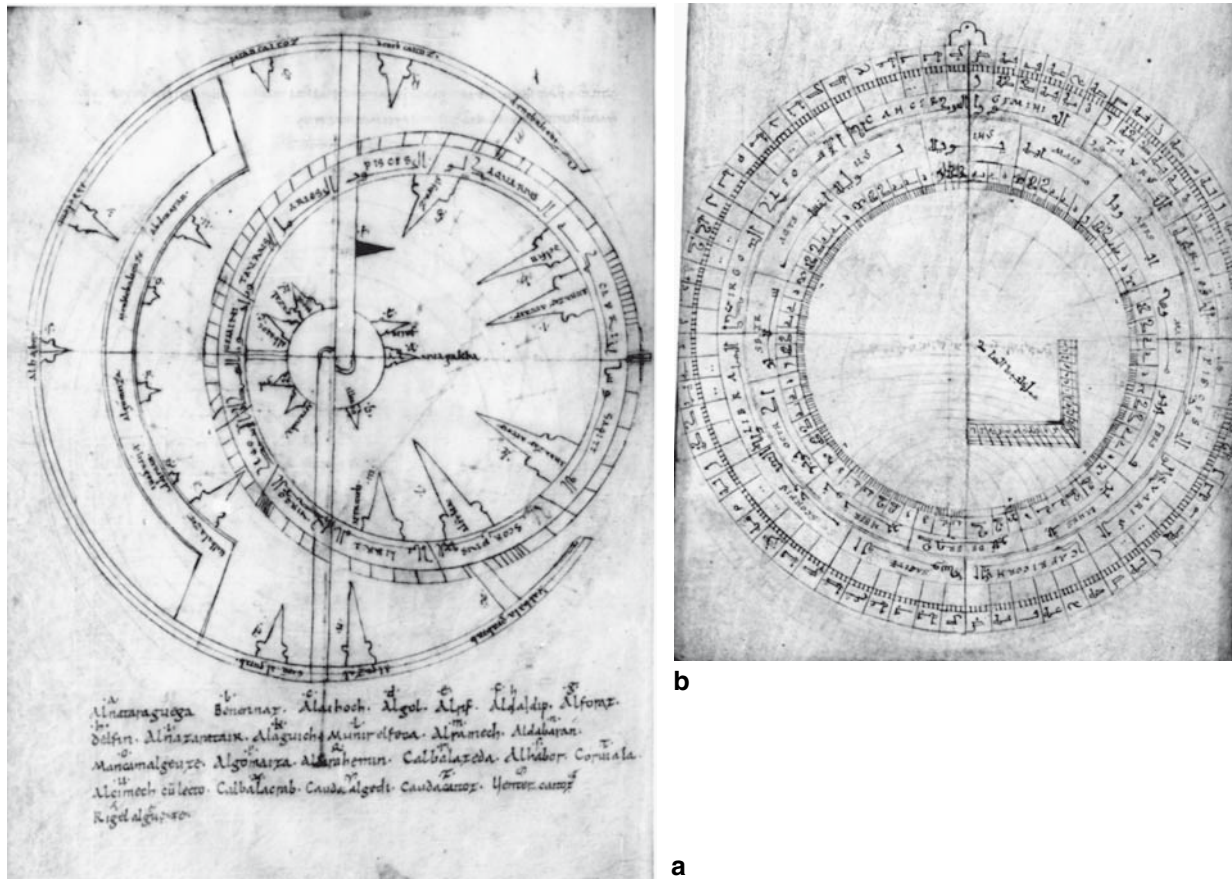
[77] On these illustrations see, most recently, Kunitzsch, "10th-Century Andalusī Astrolabe", and "Table des climats".

[78] There is a need for an investigation of the available early Arabic and Latin sources on these scales. One should perhaps start with the astrolabe treatise of Abu ʻl-Ṣalt (*ca*. 1000), which is particularly informative on the subject. This *Andalusī* astronomer wrote his treatise in *Egypt*, and he includes a table of solar longitude throughout the year for the *Syrian* calendar, and then describes the construction of scales for the *Syrian and Coptic* calendars on the back of an astrolabe (see **X-4.9** and the *addendum* to **XIIIe**, for mention of the London manuscript, which should be compared with other copies).

[79] On these see G. F. Hill, *Arabic Numerals in Europe* (1915), and King, *The Ciphers of the Monks*, pp. 309-317.

[80] Gunther, *Astrolabes*, II, pl. CXXXII opp. p. 477, for two medieval English examples (#300 and #301).

[81] See *ibid*., II, p. 347 (no. 198); North, "*Opus quarundam rotarum mirabilium*", pp. 370-372 (pp. 167-169 of the reprint); and King, *The Ciphers of the Monks*, pp. 398-399, 402-403, and 416-417.

Figs. 9.2a-b: The astrolabe came to al-Andalus in the form of the Abbasid astrolabes of 8th-, 9th- and 10th-century Baghdad, although there seems also to have been another tradition, perhaps with Roman connections (see **Figs. XIIIa-9.1a-e**). In any case, this illustration of an Andalusī astrolabe, penned by a European in the 11th century, marks an intermediate stage between the Abbasid astrolabes (see **XIIIb-c**) and the typical Andalusī astrolabes of the same century (see **Fig. X-4.1.3**). On this and the accompanying illustrations of the back and plates for the climates, see further Kunitzsch, "10th-Century Astrolabe", also **Fig. XVI-2.2** for one of the plates. [From MS Paris B.N.F. lat. 7412, fols. 19v and 23v, courtesy of the Bibliothèque Nationale de France.]

(now in the Museum of the History of Science, Oxford) (#169), is to be sought in Islamic instrumentation.[82]

In general, medieval European astrolabes display little innovation beyond the new designs of the retes and the occasional inclusion (first on English astrolabes) of calendrical scales featuring saints' days. This, of course, by no means lessens their interest as historical sources. In particular, Islamic instruments with later inscriptions in Latin, often with regional influence, or in European vernaculars, or even traces of the latter on European instruments can yield useful information on their provenance and later fate.[83] A few examples of medieval European

[82] See Gunther, *Astrolabes*, II, pp. 319-320 (no. 169), and King, "Italian Astrolabe", now in **XIIId**.

[83] Kurt Maier has made numerous contributions in this area, and it is a pleasure to acknowledge his assistance on matters philological over many years. Maier, "Monatsnamen", A, deals with European month-names in

instruments with two or more layers of inscriptions must suffice here.

Figs. 10.1a-b show a medieval astrolabe of uncertain provenance (#4556) that appeared at auction in London in 1994, catalogued in great detail by Gerard L'E. Turner.[84] The diameter is 25.8 cm. There are no original inscriptions that provide a clue to the provenance. However, it is clearly not part of the Iberian / French / English tradition. Now some of the star-pointers resemble those distinctive pointers on the earliest European astrolabe (**9**), which I suspect is partly influenced by a *Roman* tradition of astrolabe-making. Further, the plates serve the seven climates, yet another indication of early influences,[85] although the plate for the 1st climate has been reworked for latitude 43;45°, suggesting a secondary location in Northern Italy, most probably Pisa.[86] I have no reservations in supposing that it is Italian. However, there are severe problems with our understanding of the history of the astrolabe in medieval Italy,[87] and this piece certainly does not resemble any known medieval Italian astrolabes. The back bears rings for unfinished calendrical scales, which, as noted by Turner, are of a kind (also unfinished) found on some medieval English astrolabes: see **Fig. 10.2a**.[88] However, these are also found (complete) on some 11th-century Andalusī astrolabes: see **Fig. 10.2b**.[89] The star-names are in the tradition of John of London (Paris, 1246)[90] with some corrupt forms strongly influenced

vernacular on various astrolabes, including the Picard piece. *Idem*, "Monatsnamen", B, deals with European additions to various Islamic astrolabes, using unusual forms to localise the milieus of the mutations. In King & Maier, "London Catalan Astrolabe", dealing with #162 (London, Society of Antiquaries), Maier identified Catalan forms of star-names to establish the provence of the piece. His most recent study is his "Astrolab aus Córdoba", dealing with #3622 (Cracow, Jagellonian University Museum, inv. no. 4037-35/V), an unsigned astrolabe with Arabic inscriptions made in Cordova in 1054 and bearing later Catalan inscriptions.

[84] See *Christie's London 29.09.1994 Catalogue*, pp. 34-39 (lot 136), with several photos of details.

[85] See King, "Geography of Astrolabes", pp. 7-8, now in **XVI-2**.

[86] I am grateful to Siegfried Müller (Ashaffenburg) for drawing my attention to the fact that 43;45° is given as the latitude of Fano and Pisa by Ptolemy. To assume that, say, Pisa was intended, it would be necessary and is reasonable to assume that this item of information from Ptolemy's *Geography* was available to whoever modified the plate. The Renaissance Latin versions of the *Geography* depend entirely on the Byzantine Greek tradition, and there are more than 40 surviving Latin manuscripts from the 15th century (Berggren & Jones, *Ptolemy's* Geography, p. 52, and Swerdlow, "The Recovery of the Exact Sciences of Antiquity in the Renaissance", pp. 160, 164).

Medieval tables offer no alternatives. A medieval Italian geographical table copied around 1475 and published by John North has no localities in Italy with latitudes between 43;30° and close to 44;30°. It gives 43;10° for Florence and Fermo, 43;30° for Pisa and Pistoia, then 44;24° for Forli and 44;30° for Verona. See North, *Horoscopes and History*, p. 193.

[87] See King, "Italian Astrolabe, pp. 29-32, now in **XIIId-1.1**.

[88] Examples cited by Turner are #300 (Gunther, *Astrolabes*, II, pp. 477-478) and #301 (*ibid*., pp. 478-479).

[89] See, for two examples, #116, described in Woepcke, "Arabisches Astrolabium", pp. 5-6, and beautifully illustrated in *Paris IMA 2000-01 Exhibition Catalogue*, pp. 196-197; and #118, discussed in Gunther, *Astrolabes of the World*, pp, 253-256 (no. 118) and Pl. LX; and for an explanation in English, *ibid*., pp. 266-267 (*ad* #124), after Sarrus.

[90] Kunitzsch, *Sternverzichnisse*, pp. 39-46 (Typ 6); also *idem*, "John of London and his Unknown Arabic Source". On the identity of the author see Knorr, "John of London".

Knorr (*ibid*., pp. 309-310) mentions an astrolabe designed by John of London that was made by his disciple Roger of Lincoln and was used in 1250 to correct the former's star-table. In passing we note that there is an astrolabe of French design with a mark of ownership "I LOND" in the National Maritime Museum (#3058—inv. no. A60/NA66-12), that bears closer investigation. The plates serve a series of latitudes (Carthage, Tunis, Armenia, Rome, Cremona and Paris) but there is an additional one for London and Lincoln (latitudes 52° and 53°). Years ago I would have said that this was a 14th-century piece, but it could well be 13th-century.

by the Arabic originals (such as BAFAZ for *bedalferaz* from *yad al-faras*).[91] Some unusual forms such as SELLA for α UMa (a "saddle" on the back of the Great Bear, perhaps an interpretation of what is *super dorsum eius*) are remarkable.[92] WEGA is not what one would expect of an Italian engraver, although an astrolabe made in Urbino in 1462 (#4506—see below) has VVEGA, following the textual tradition. In particular, the distinctive and unique rete design, with a frame within the upper ecliptic reminiscent of a bishop's mitre, and a curious socle underneath it, as well as a misshapen trefoil at the bottom of the rete, raises a host of questions that I hope will be addressed when serious interest in medieval instruments becomes more widespread. Certainly, this is a piece that demands further study. Turner cautiously labelled it "European", adding that "both Italy and England are contenders". England can now be dropped.

Figs. 10.3a-f display a 14th-century French astrolabe of exceptional historical interest (#202). The numbers on it are in a notation totally different from the Roman and Hindu-Arabic ones, and unrelated to any alphanumerical ones; this notation was used mainly but not exclusively in monastic circles from the 13th to the 16th century.[93] This notation, involving solely rectilinear segments, is the most sensible ever designed by man when it comes to engraving numbers on metal or on wood (it was also used on wine-barrels). The design of the rete is typically French, with a short equinoctial bar perpendicular to the upper vertical axis, and half-quatrefoil decoration.[94] The month-names on the back of this astrolabe are in the medieval Picard dialect, which pinpoints the provenance. The mater bears a second layer of inscriptions, indicating that the Benedictine monk of Liège, Paschasius Berselius, gave the piece to his teacher of Greek in Louvain, Hadrianus Amerotius, in 1522. The use of monastic ciphers on the Picard astrolabe alone renders it one of the most interesting instruments known from the Middle Ages, but its later history in the hands of two Humanists of Liège and Louvain is almost as intriguing.

Figs. 10.4a-c display three Italian astrolabes likewise of exceptional historical interest: the first, a very medieval-looking 14th-century piece (#493),[95] whose rete-design clearly inspired the maker of the second (#4506), very Renaissance-looking piece dated Urbino, 1462.[96] An astrolabe with the same rete-design as the latter was copied in the intarsia in the study of the Archduke Federico da Montefeltro in his palace at Urbino, built in 1476.[97]

Figs. 10.5a-e show the front and back and some details of another Italian astrolabe (#548), probably 14th-century, but bearing later engravings by a 15th-century Parisian astronomer.[98]

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[91] On this corruption see Kunitzsch, *Arabische Sternnamen in Europa*, pp. 85-86.

[92] On this star-name see now Dekker, "Astrolabe Stars", p. 189, n. 49.

[93] On this piece, within the context of the history of the monastic ciphers, see King, *The Ciphers of the Monks*, especially pp. 131-151 and 406-419. On the Picard connection see also Maier, "Romanische Monatsnamen", A, pp. 240-242.

[94] See further **XIVc-2** and **XVII-3**.

[95] Florence, Museo di Storia della Scienza, inv. no. 1107: now published—see n. 97.

[96] Formerly Musée Départemental d'Alliers, Moulin (stolen in 1973): published on the basis of photos of the front and back—see next note.

[97] See King, "Urbino Astrolabe", which also contains the first descriptions of #493 and #4506.

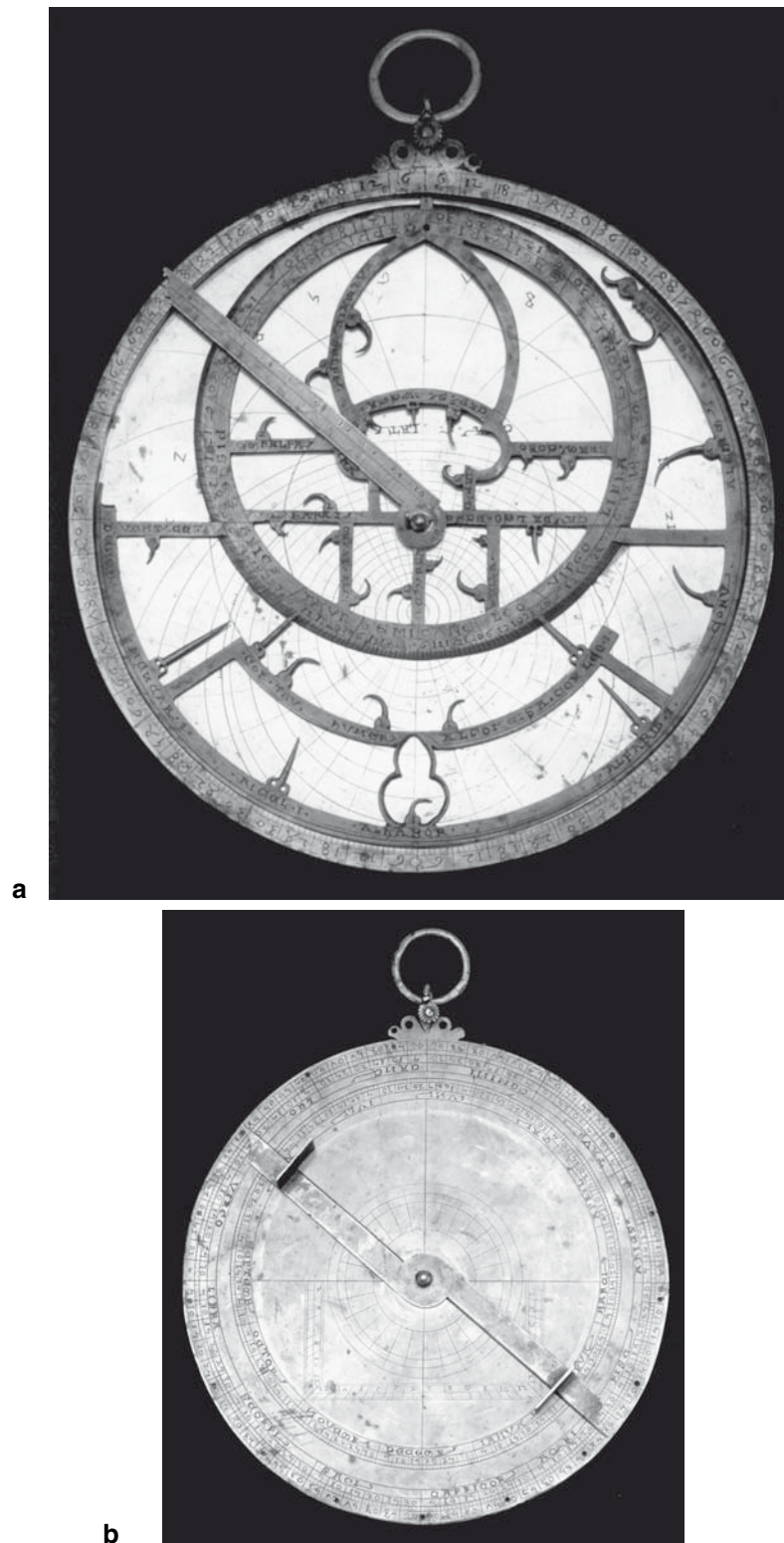
[98] Nuremberg, Germanisches Nationalmuseum, inv. no. WI 6: see King, "Nürnberger Astrolabien", II, pp. 578-581 (no. 1.74).

Figs. 10.1a-b: The front and back of the remarkable astrolabe that came to light some 10 years ago (#4556). [Private collection; photos courtesy of Christie's, London.]

Fig. 10.2a: Surely, the incomplete scale on the back of the medieval astrolabe (#4556) is mirrored in this scale on the back of a medieval *English* astrolabe (#300). [Courtesy of the Museum of the History of Science, Oxford.]

When an instrument is not understood and has been labelled a fake, it is useful to consider it in the light of other instruments by the same maker or from the same workshop. This was the fate and then salvation of an astrolabe (#640),[99] dedicated in 1462 by the German astronomer Regiomontanus to his patron, the Cardinal Bessarion. **Figs. 10.6a-d** show details of this and of two out of ten other astrolabes in the Regiomontanus tradition (#452[100] and #549[101]).

No regional studies of astrolabe-making in medieval Europe have been conducted yet.

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[99] England, private collection: see King & G. Turner, "Regiomontanus' Astrolabe", and the earlier literature there cited. On Regiomontanus see already Zinner, *Regiomontan* (also available in English); and the article by Edward Rosen in *DSB*.

John North, referring to our study in "Review of Turner, *Studies*, B", pp. 485-486, rightly points out that every argument we proposed to establish the authenticity of this piece could be countered by a sceptic. He seems to be unaware of the absurd claims ("looks like a Hartmann astrolabe", "kitchen Latin", *etc*.) that first led to the Regiomontanus astrolabe being returned to Christie's after the 1989 auction and then led to our attempt to establish its authenticity by countering all of those claims. North conveniently omits any reference to all the other German astrolabes that I identified in the 80s, one by the same maker, and the others from related workshops. Turner and I described the 1462 piece in the context of all the others, and adduced (p. 186) a text by Georg Hartmann (1527) mentioning a feature of the astrolabes of Regiomontanus that he himself had seen, and which is found on the 1462 piece.

[100] Paris, private collection: see King & Turner, "Regiomontanus' Astrolabe", p. 189, n. 54.

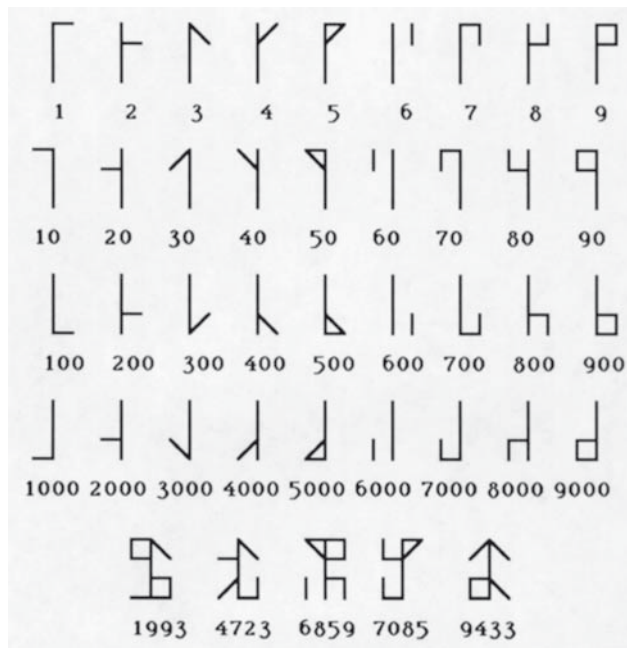
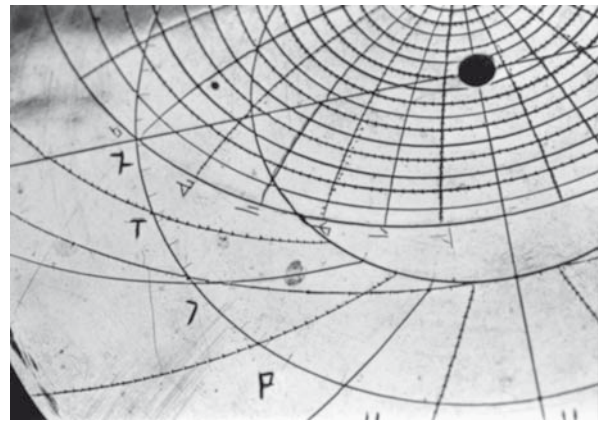
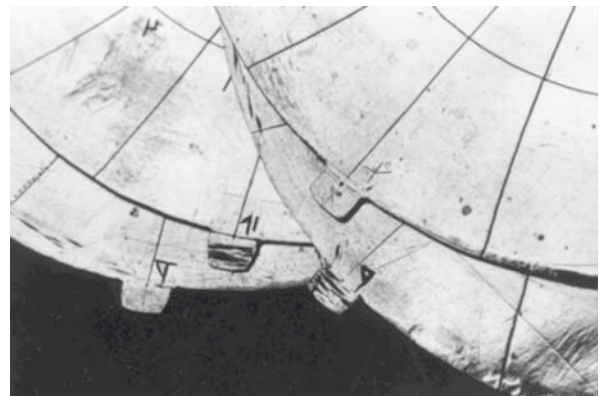
[101] Nuremberg, Germanisches Nationalmuseum, inv. no. WI 129: see King, "Nürnberger Astrolabien", II, pp. 582-586 (no. 1.75).

Fig. 10.2b: There is no need to suppose that #4556 was made in England, for it is clear that neither the astrolabists in Italy nor in England knew what to mark on these scales. What is supposed to be engraved there is found on Andalusī astrolabes from the 11th century, such as this piece by Ibrāhīm ibn Saʿīd al-Sahlī in Toledo in 460 H [= 1068]. Here we find the calendrical scales that are missing from the European astrolabes illustrated in **Figs. 10.1b** and **10.2a**. They display a kind of perpetual calendar, enabling the user to find the day of the week from the date within a 28-year solar cycle: see also **Fig. X-4.7.2**. The front of this piece is illustrated in **Fig. XIIIc-9o**. [Courtesy of the Museum of the History of Science, Oxford.]

Figs. 10.3a-f: (a-b) The front and back of the Picard astrolabe with monastic ciphers (#202).
(c) This notation, in its simplest form of Greek origin, was developed by Cistercian monks in the 13th and 14th centuries, and was used in restricted circles for various purposes.
(d) The details show the additional markings found on the plate for 51°, confirming the provenance already evident from the original textual inscriptions.
(e) The latitudes of the plates rendered in ciphers.
(f) An inscription on the mater reveals that the piece changed hands within the Humanist circle of Louvain in 1522.
[Private collection; main photos courtesy of Christie's of London, with details by the author.]

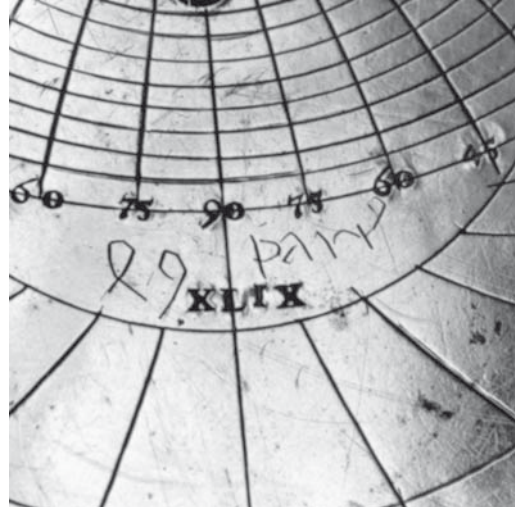
Figs. 10.3b

1 2 3 4 5 6 7 8 9
10 20 30 40 50 60 70 80 90
100 200 300 400 500 600 700 800 900
1000 2000 3000 4000 5000 6000 7000 8000 9000
1993 4723 6859 7085 9433
c
d
e

f

Figs. 10.3c–f

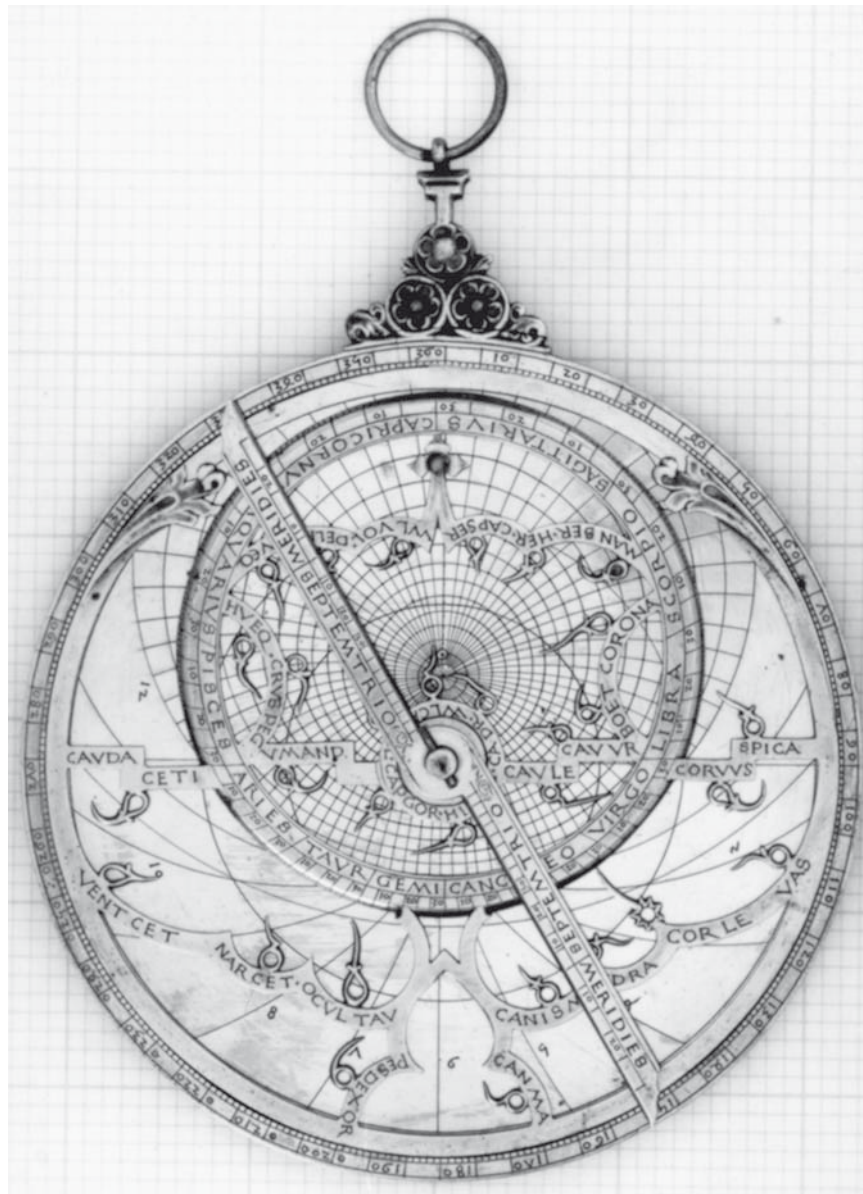
Figs. 10.4a-c: (a) This medieval Italian astrolabe (#493), preserved in Florence, has a distinctive rete pattern that was clearly popular. Note the small frame shaped like a wine glass below the ecliptic. [Photo courtesy of the Istituto e Museo di Storia della Scienza, Florence.]

(b) A Renaissance astrolabe with identical design but very different aspect and engraving, dated 1462 and actually made in Urbino (#4506), was stolen in 1973 from the Musée départemental in Moulins (Alliers) and has not been recovered. The basic design of the rete inspired the 15th-century Vienna school, and especially Johannes Stöffler *ca*. 1525 (see #253). [Photo courtesy of the late Alain Brieux, Paris.]

(c) The astrolabe depicted in the Urbino intarsia. Note the similarity to those illustrated in **Figs. 10.4a-b**. [From King, "Urbino Astrolabe", p. 102, courtesy of the editors.]

Figs. 10.5a-e: (a-b) This medieval Italian astrolabe (#548) has quatrefoil decoration on the rete and animals on the back that have elsewhere been shown to be English (Ackermann & Cherry, "Three Medieval English Quadrants"). This merits further investigation. [Courtesy of the Germanisches Nationalmuseum, Nuremberg.] Figs. 10.5c-e: Some details of the instrument. [Photos by the author, courtesy of the Germanisches Nationalmuseum, Nuremberg.]

(c) The piece also bears additional markings (or rather scratchings) indicating that it was put together (*composuit*) by Henricus de Hollandia, a student of Jean Fusoris, probably in Paris *ca*. 1425. On Henricus de Hollandia see also Poulle, "L'horloge planétaire d'Henri Arnault de Zwolle", and the references there cited.

(d) But in the 16th century the piece came into the hands of a German craftsman, probably in Nuremberg. In addition to the original Italian numerals on the rim (c), Henricus scratched the latitudes on the plates, here 49° for *Pari(si)us*, and the German later punched the equivalent in Roman numerals.

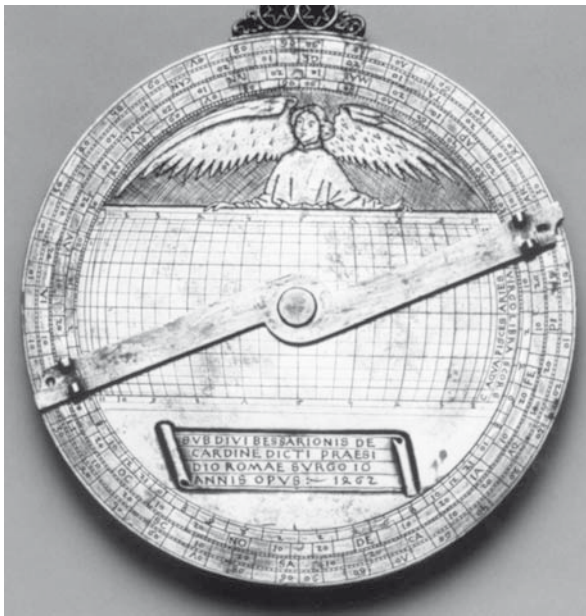
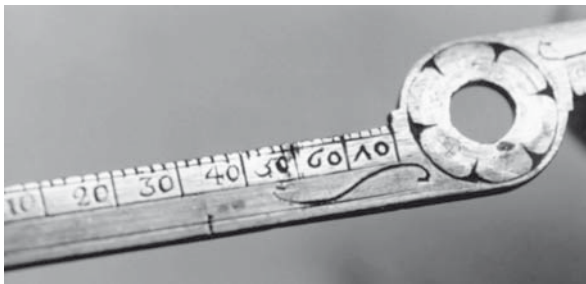
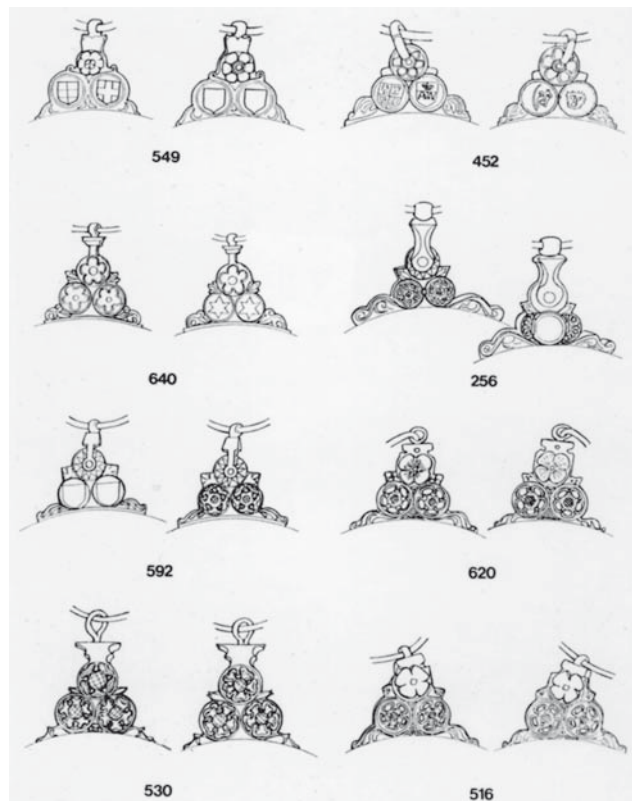
(e) On the scales on the back the three sets of engravings can be seen side by side: Italian (month-names), French (scratchings for numbers) and German (numbers, different from those in (e), with a second 10 in error for 12).

a

Figs. 10.6a-b: (a) This elegant astrolabe (#640) caused something of a stir in "the trade" when it was auctioned in London in 1989. Soon thereafter it was declared dubious by would-be experts. It took considerable effort to show that it was not. In King & G. Turner, "Regiomontanus' Astrolabe", it is shown to be one of eleven surviving astrolabes from the same workshop.

(b) The dedication indicates that the piece was presented by Johannes (Regiomontanus), the leading European astronomer of the mid 15th century, to his patron Cardinal Bessarion. The text contains some brilliant plays on words, as well as various anagrams and chronograms. The maker's name can be determined from the anagram RGO IO, which is sufficient to identify him as IOannes de Monte ReGiO. The gift was for the occasion of the 400th anniversary of the 1062 Byzantine astrolabe shown in **Figs. 4.1a-b** (the date 1062 is there in a chronogram, and reading downwards we find the anagram SVB C D ANNIS, "after 400 years"). The expression OPVS DICTI DE CARDINE DIVI is a translation of an inscription on the 1062 astrolabe, and these words are used in quite different contexts in plays on words in the dedication. And there is a lot more. See Holzschuh & King, "The Earliest Renaissance Instrument Deciphered".

b

c

d

Figs. 10.6c-d: (c) The rete of another from the same workshop (#452), doubtless made by the same craftsman, uses the "medieval" Arabic star-names, whereas the 1462 piece uses the "Renaissance" star-names in Latin.

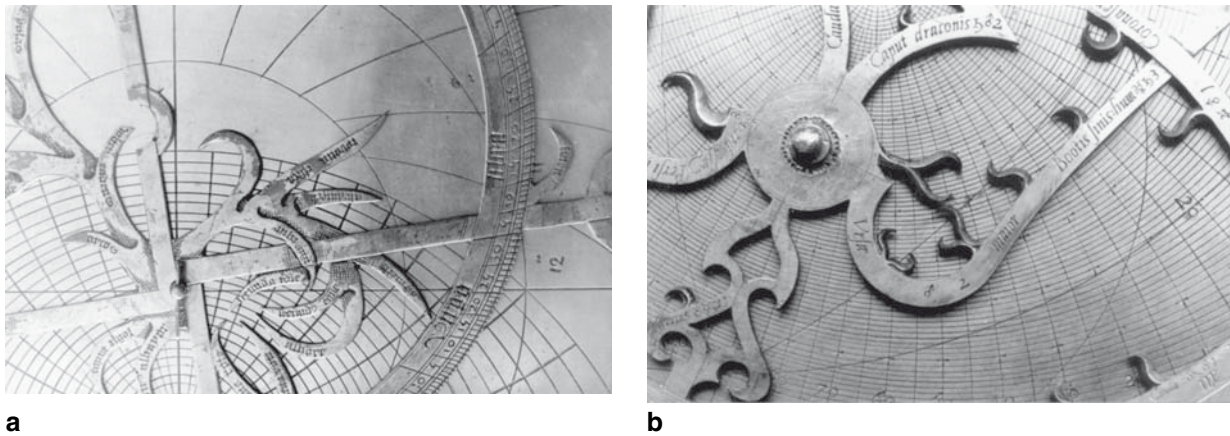
(d) The fact that this diametric rule on a Regiomontanus-type astrolabe dated 1457 (#549) was broken and then repaired is graphically illustrated by the difference between the Renaissance numbers on the repaired part (up to 50) and the original medieval Gothic markings (60-70).

[Photos of #640 courtesy of the National Maritime Museum, Greenwich, and Christie's of London; photo of #452 from a private collection in Paris, taken by Gerard L'E. Turner, courtesy of the owner; photo of #549 by the author, courtesy of the Germanisches Nationalmuseum, Nuremberg.]

e

(e) The thrones on various astrolabes of the Regiomontanus type. [From King, "Astronomical Instruments between East and West", pl. 12 on p. 160; artwork by Helen Waldman.]

a

b

Figs. 10.7a-b: (a) The pointers for the stars of the Great Bear on a remarkable astrolabe (#536) from *ca*. 1300 (?). The provenance of this piece is uncertain but most probably French. It is significant that the star-catalogue in the treatise on astrolabe construction by Jean Fusoris (Paris *ca*. 1400) lists these stars. The plates serve 44°, 46°, 49° and 52°, a combination that also suggests a French provenance. [Photo by Professor Gerard L'E. Turner, courtesy of the Museum Boerhaave, Leiden.]

(b) The pointers for the stars of the Great Bear on a typical astrolabe from 16th-century Louvain (#555). The inclusion of these stars is evidence of the influence of a medieval tradition yet to be researched. [Photo by the author, courtesy of the Germanisches Nationalmuseum, Nuremberg.]

Sometimes the dearth of materials can make this a daunting task. For example, to cite the case of the Low Countries, we know (a) that there was an astrolabe in a monastery in Liège already in the 11th century (we have the correspondence in which this instrument was requested on loan by a monastery in Cologne and refused[102]); and (b) that a treatise on the use of the astrolabe was compiled by Henry Bate in Malines in 1274.[103] Yet not a single astrolabe survives that was clearly made in the Low Countries before *ca*. 1540. There is one possible exception (#536),[104] a spectacular astrolabe with unusual design betraying various French influences but which nevertheless could be from the Low Countries (see **Figs. 10.7a-b**). And then, within a few years, Louvain had become the leading centre of instrument-production in Europe.[105]

For a taste of what we are missing we might mention an astrolabe with Armenian inscriptions (#3800)[106] made *ca*. 1700 by an Armenian who had studied in Amsterdam—see **Fig. 10.8**. His

[102] See Tannery & Clerval, "Correspondance".

[103] Published from an Oxford manuscript in Gunther, *Astrolabes*, II, pp. 367-376. The work recently published in Lorch, "Astrolabe Treatise of Rudolf of Bruges", does not seem to have a Flemish connection beyond the name of the author.

[104] Leiden, Museum Boerhave, inv. no. 3102: see van Gent, *Leiden BM Astrolabes*, pp. 20-28. The plates serve 44°, 46°, 49° and 52°, a combination which also suggests a French provenance. Yet there is more to be said about this piece.

[105] The splendid *Madrid 1997 Exhibition Catalogue* takes our understanding of this scene a monumental step forward.

[106] Burakan Astrophysical Observatory, Armenia: see Tumanyan, "Armenian Astrolabe". On the Armenian alphanumerical notation see Ifrah, *Histoire des chiffres*, I, pp. 542-543.

Fig. 10.8: The front of an astrolabe with Armenian inscriptions (#3800), with numbers in Armenian alphanumerical notation. This is the only such instrument known, and it was made *ca*. 1700 by Ghoukas Vanandetsi, who had worked in Amsterdam. The rete bears no relation whatsoever to contemporary Islamic designs; rather, it is based on a medieval Dutch or German rete. (Vaguely similar rete patterns are illustrated in a medieval German astrolabe treatise.) Since no early astrolabes survive from the Low Countries, this piece is of prime historical importance. [Property of the Burakan Astrophysical Observatory, Armenia. Photo from the Ernst Zinner Archives at the Institut für Geschichte der Naturwissenschaften, Frankfurt am Main.]

a

Figs. 10.9a-b: (a) On the rete of this Iranian astrolabe, the *basmala*—the formula *bi-sm^i ʻllāh^i ʻr-raḥmān^i ʻr-raḥīm*, "In the name of God, the Merciful and Compassionate"—is written very naturally, by the liberal and flexible standards of Arabic calligraphy, in mirror script. The piece (#3550) was made by Muḥammad Zamān in Meshed in 1062 H [= 1651/52]. Neither this nor any other instruments by this maker reveal any European influence. It would be comforting for my hypothesis to find an *basmala* in mirror script on any Iranian metal object from before *ca*. 1500. [Courtesy of The Metropolitan Museum of Art, New York.]

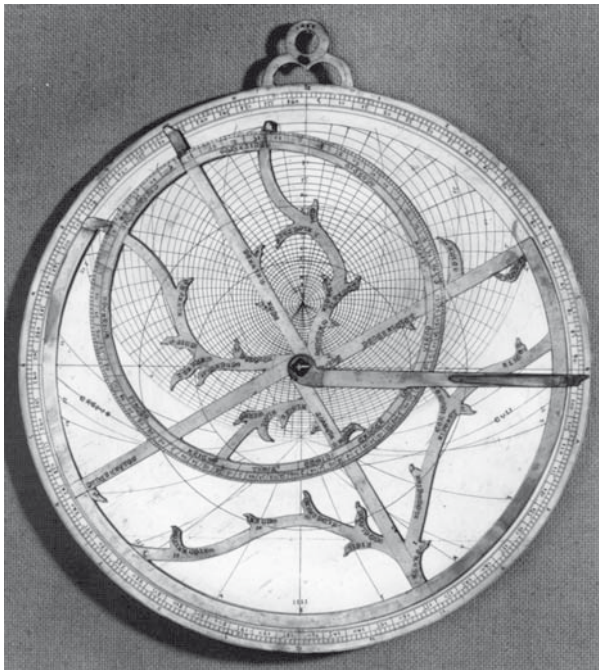
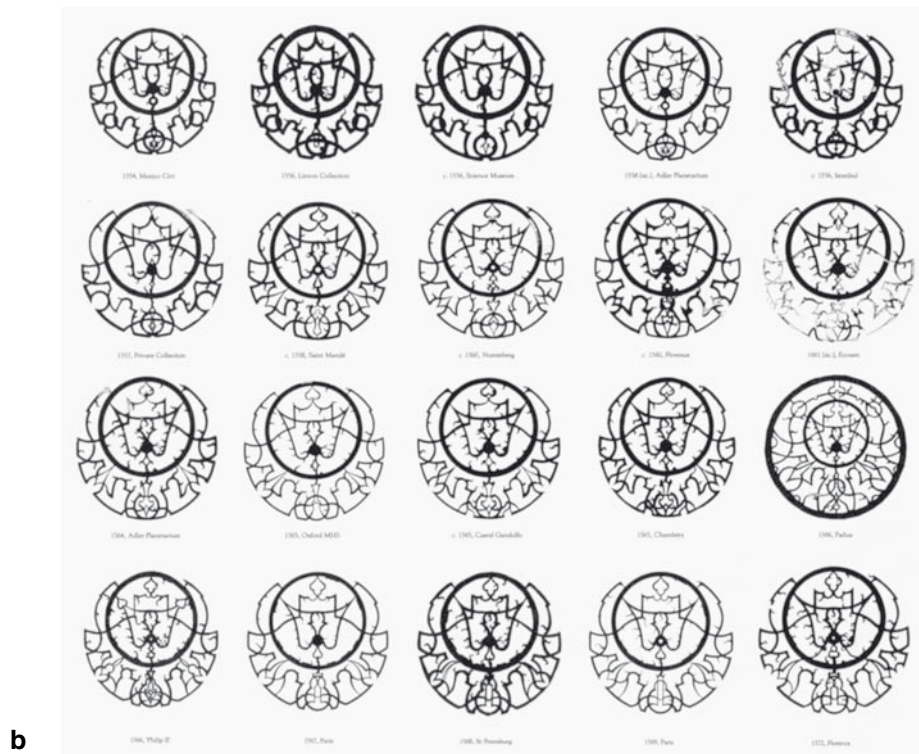
(b) Some of these Flemish astrolabes from the 16th century exhibit frames in very similar form. Were these modelled on an Islamic astrolabe?? [From van Cleempoel, *Louvain Astrolabes*, p. 48, with permission of the author.]

(c) Or was the basic "tulip" design available to Mercator on medieval astrolabes? This piece dated 1468 (#550) is in a medieval tradition, even though it is contemporaneous with the Regiomontanus-type astrolabes (**Figs. 10.6a-d**). The latitude-related markings were started for 49° and finished for *ca*. 46;30°. [Courtesy of the Germanisches Nationalmuseum, Nuremberg.]

(d) In any case, a very Islamic-looking but also very Flemish-looking rete is found on an astrolabe by Muḥammad Muqīm al-Yazdī *ca*. 1650 (#1051). The relationship between the two schools of rete design merits further investigation. [Courtesy of the National Maritime Museum, Greenwich.]

b

c

d

astrolabe design, which is quite unrelated to contemporary Islamic designs,[107] and is surely based on a much earlier, indeed medieval, Dutch astrolabe!

Only once the medieval instruments have been properly studied can one hope to properly understand the Renaissance instruments of, say, Louvain and London.[108] At least these have now been catalogued.[109] The only features that appear for the first time on Renaissance astrolabes appear to be wind-roses (the earlier Islamic variety[110] does not appear on Islamic astrolabes), and the markings for converting time in seasonal hours to equinoctial hours and *vice versa* (based on trivial mathematics).[111] Rete-design is, of course, another matter, although the more we learn about Islamic and medieval European models, the better we can place the Renaissance ones. One may wonder, for example, which came first: the *basmala* on Iranian astrolabes[112] written in mirror script[113] or the so-called "tulip"-shaped frames[114] on retes from Louvain—compare **Figs. 10.9a-b**. The inscriptions on certain 15th-century Iranian and Central Asian astrolabe retes may serve as examples as the talent of Muslim craftsmen for such exquisite decoration.[115] In any case, if the inspiration for the Remaissance Louvain design is not to be found in Islamic calligraphy, it should be sought in medieval Europe: see **Fig. 10.9c**.

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[107] Until 1998 this was the only Armenian astrolabe known. In that year an astrolabe with distinctive Iranian design, but with inscriptions in Armenian and dated 1479, appeared on the scene. This piece (#4220), described in *Paris Drouot 19.12.1997 Catalogue*, is now in a private collection.

[108] See my "Review of G. Turner, *Elizabethan Instruments*", especially pp. 148-150.

[109] G. Turner, *Elizabethan Instruments*", and van Cleempoel, *Louvain Astrolabes*.

[110] See, for example, Wieber, "Seekartogramm".

[111] On this see, for example, Michel, *Traité de l'astrolabe*, pp. 42, 85-86 and 90.

[112] On #3550—New York, Metropolitan Museum of Art, inv. no. 63.166—see King, *Mecca-Centred World-Maps*, p. 189, with an illustration of the back.

[113] Mirror script (called *muthannā* in Arabic or *aynalı yazı* in Turkish) is fully within the historical tradition of Arabic calligraphy and calligraphic ornamentation. The earliest example known to me is on a silk fragment from 13th-century Granada (see **Fig. XV-16**), although there are surely earlier examples. Alas, I lost my most useful reference book on Arabic calligraphy—see n. 16 to **XIIIa-3**—in which I still recall seeing some. For some late examples, see Safadi, *Islamic Calligraphy*, pp. 31 and 137; and Schimmel, *Calligraphy and Islamic Culture*, pp. 32, 84, 113, and n. 59 on p. 171 and the article "Khaṭṭ" in EI_2, esp. col. 1124b (Iran), and col. 1126a and Fig. 12 in Pl. XXXIX (Ottoman Turkey), as well as Derman, *The Sultan's Signature*, pp. 160-161 with an illustration of a *basmala* in *muthannā* script by the Turkish calligrapher Ismail Hakki (d. 1946).

None of the many inscriptions illustrated in Melikian-Chirvani, *Iranian Metalwork in the V&A*, is in mirror script, but neither are there any astrolabes featured in that book, even though there are some *Iranian* astrolabes in the collection on which this otherwise splendid catalogue was based!

Historians of art are generally incapable of understanding that astronomical instruments are both "metalwork" and "works of art", and that they constitute the largest corpus of art works still to be investigated from an art-historical point of view. (This holds for both Islamic and European instruments.) But that is not the only problem confronting historians of that "figment of the imagination" known as "Islamic Art": see Melikian-Chirvani, "Toward a Clearer Vision of 'Islamic' Art".

[114] The term "tulip" is used advisedly, not least because these frames do not really resemble tulips. It seems uncontested that the tulip was introduced in Holland from Turkey in the 16th century. On the frames on Louvain astrolabes see already the insightful remarks in van Cleempoel, *Louvain Astrolabes*, pp. 46-51. If the Louvain retes were inspired by an Islamic *basmala*, one still has to "explain" the frames outside and below the ecliptic. As van Cleempoel remarks, these are intimately connected to the frames within the ecliptic.

[115] A particularly spectacular example from the 17th century is shown in **Fig. XIVd-2.1b**. See also the 13th-century palindrome in **Figs. XIVb-3.1c-d**.

11 The quadrant in medieval Europe

We now know that the so-called *quadrans vetus*, a combination of a universal horary quadrant fitted with a solar declination scale and a superposed shadow-square, which was first introduced in Europe in the late 12th century is of Islamic provenance. All other European quadrants, mostly of the trigonometric variety, and known only from textual sources, are also of Islamic origin. This includes the sexagenarium and the meteoroscope.[116] The details of the transmission to Europe are unclear.[117] The *quadrans novus* of Profatius (*ca*. 1300) is an unhappy combination of two unrelated sets of markings: firstly, a universal horary quadrant fitted with shadow-square and cursor—that is, the early Islamic *quadrans vetus*—and secondly, a stereographic projection of the ecliptic and a series of horizons for different latitudes. The horary quadrant determines time approximately without using the ecliptic and the horizons; these are useless for the main operations of timekeeping because there are no altitude circles. The other side of the instrument was fitted with a sine quadrant to perform the operations of time-keeping using trigonometric formulae. This bastard instrument was popular in Europe but unknown in the Islamic world.[118]

12 Concluding remarks

In this brief overview, I hope to have conveyed some of the results of recent research on medieval Islamic and European astrolabes, and to have shown the importance of investigating the instruments in the light of contemporary textual sources. There is material here for the historian of astronomy, the historian of mathematics, the specialist on Arabic manuscripts, the art historian, and the student of Arabic, Hebrew and Latin calligraphy. Although—at least from a scientific point of view—many of the most interesting developments are recorded only in manuscripts and not attested on surviving instruments, remarkable instruments still keep turning up.

The surviving astrolabes, be they Islamic or European, are a rich source for the study of the development of various astronomical, geographical and mathematical concepts, let alone technology and decorative art. They have never previously been systematically exploited for the names used for stars on representations of the heavens, for the latitudes that were used for specific localities, or for the various scales and trigonometric grids used to facilitate various calculations. Modes of construction changed over the centuries, and the decoration used for star-maps had to be modified because stars move relative to the ecliptic (the longitude increases linearly with time although the latitude remains unchanged) and to the celestial equator (both right ascension and declination change irregularly). The closer one looks at these instruments, the more one can learn about the development of numeral forms, the application of new

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[116] On the former see Poulle, "Sexagenarium", and now Aguiar & Marrero, *Sexagenarium*. On the latter see North, "Meteoroscope".

[117] See Lorch, "Sine Quadrant".

[118] On the *quadrans novus* see now **X-6.5**, **XI-10.3** and **XIIa-8**.

mathematical techniques in astronomy,[119] the geography of the instruments (where they were made and the places for which they were intended),[120] local variations in Islamic religious practices (prayer at specific times in a specific direction) and Christian saints' days, and the ingenuity of the medieval mind and the diversity of medieval culture. The inscriptions—particularly the names of the months and zodiacal signs, and occasionally even star-names—can often be used to localise the provenance of an instrument when these are in local forms of Latin or in vernaculars. The positions of the stars on medieval European astrolabe retes present a challenge of their own, for it is of little interest to show that they seldom correspond to reality; rather, it is more worthwhile to compare them with contemporaneous star-catalogues.[121] The technological aspects of these medieval astrolabes have mainly been ignored to date; fortunately, we have some reliable studies of later instruments that set the standards for future investigations.[122] Futhermore, many of these medieval astrolabes are scientific works of art. To obtain a feeling for the sheer beauty of some historical instruments, the reader is recommended to visit the major collections in Oxford or Greenwich, Florence or Nuremberg, Chicago or Washington, or to leaf through various lavishly illustrated books.[123]

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[119] These are especially evident in the form of graphical representations of mathematical functions. See North, "Graphical Representation of Functions in Medieval Astronomy", and, with many more examples, Charette, "Numbers and Curves", as well as *idem*, *Mamluk Instrumentation*, *passim*.

[120] See n. 3.

[121] See n. 36.

[122] See the studies cited in n. 33.

[123] Such as Michel, *Instruments*; A. J. Turner, *Instruments*; and G. L'E. Turner, ed., *Strumenti*. Some of the splendid instruments in Belgian collections are featured in *Brussels SG 1984 Exhibition Catalogue*. For a tour through a library of early European books on instruments, especially astrolabes, in the company of a guide with a sense of humour, see Simcock, "Rambles".

Part XIIIb

The oldest known astrolabe, from 8th-century Baghdad or What nobody knew was in the Archaeological Museum in Baghdad: The oldest astrolabe in the world

To the memory of some of the Iraqi scholars who were seriously concerned
with the cultural heritage of their country:
Bashīr Faransīs, Nāṣir al-Naqshabandī, ʿAbbās al-ʿAzzāwī and Jirjis ʿAwwād,
and also Issam El-Said

DEDICATION, ACKNOWLEDGEMENTS AND NOTES TO THIS VERSION

A tiny undated astrolabe formerly in the Archaeological Museum at Baghdad is here shown to date from the late 8th century, or at the latest, the first quarter of the 9th century, that is, the time of the first Muslim encounters with Hellenistic science. It has precisely the form of the simplest astrolabes with Greek inscriptions, astronomical markings for a set of stars from a Greek star-list, whose positions were derived using the (inaccurate) Greek value of precession, and latitude-related markings for the seven climates of Greek Antiquity. Some detective work is needed to look behind a layer of inscriptions added almost a thousand years after the astrolabe was made. The instrument is here compared with a Byzantine astrolabe dated 1062, which is the only surviving astrolabe with Greek inscriptions, and various early Islamic astrolabes from the late 9th and 10th centuries, all made in Baghdad. This Baghdad astrolabe is a symbol of an unprecedented (and unparalleled) episode of trans-cultural scientific transmission, immediately preceding the remarkable Renaissance in mathematical astronomy and astronomical instrumentation that took place in Baghdad in the 9th century.

I wrote this study in the Spring of 2003, during the invasion and occupation of Iraq by a very ill-advised military force, with the war profiteers ready to move in behind them. As I prepare this version in the Spring of 2004 for inclusion in this volume, the folly of this adventure is becoming apparent even to some of its advocates. Alas, it is the Iraqis who will pay most dearly for this attempt to bomb them into democracy. A documentation centre on the Iraqi cultural heritage as represented in museums and libraries has been established at the Oriental Institute of the University of Chicago.* In order to stay sane during 2003 I prepared a website listing all of the research that has been conducted to date on the Renaissance of astronomy in Iraq, which occurred at a time when Baghdad was the most civilized city in the world and people there were involved in sensible things like writing history, studying language, discussing theology, reciting poetry, and making astrolabes.**

My hope is that the little Baghdad astrolabe has survived this period of horror, and that there will be enough sensible people left in Baghdad to one day appreciate its significance. Certainly there were people there 50-odd years ago who were seriously involved with the conservation and documentation of their cultural heritage, and this paper is dedicated to the memory of four of these scholars. Likewise, I pay tribute to the Iraqi-born scholar Issam El-Said (1938-88), who found exile in England, for his splendid book *Islamic Art and Architecture: The System of Geometric Design*, Reading (U.K.), 1993, the only work on the subject known to me which mentions geometry and numbers.

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* See http://oi.uchicago.edu/OI/IRAQ/iraq.html.

** See www.uni-frankfurt.de/fb13/ign/astronomy_in_baghdad/bibliography.html.

TABLE OF CONTENTS

1 Introductory remarks

1 The occasion of this study

One of my less violent reactions to the horrendous events that occurred in Iraq during the Spring of 2003 was to excavate from my unpublished and incomplete catalogue of medieval Islamic and European astronomical instruments (see **XVIII**) a description of what is, without a doubt, *the oldest known astrolabe*: see **Figs. 1-4**. For it was made in Iraq, and it was made before the astounding developments in astronomy and astronomical instrumentation that occurred there in the 9th and 10th centuries.[1] In fact, I have no hesitation in assigning it to the late 8th century, that is, to the period when the Muslims were first coming into contact with Hellenistic (as well as Indian and Iranian) astronomy. Alas, I cannot write that it is the oldest *surviving* astrolabe, for until recently the instrument was preserved in the Archaeological Museum in Baghdad. So we shall have to wait and see whether this precious piece and the other, far less historically important, astrolabes in the Baghdad collection have survived (see the **Appendix** for a list of these).

2 The early history of the astrolabe and the oldest surviving examples

The astrolabe is a Greek invention.[2] We have a Greek text on the astrolabe by Philoponos (*ca*. 625) and a Syriac text by Severus Sebokht (*ca*. 650).[3] Only one astrolabe with inscriptions in Greek survives to this day:

- ❖ a Byzantine piece dated 1062 (#2—1.1.1), preserved in the Museo dell'Età Cristiana in Brescia, which is signed by one Sergios, apparently a Persian (?), and seems to have been constructed in Constantinople. It was published in 1926,[4] but since then has not received the attention it deserves. See **Fig. 5** and also **XIIIa-4**.

We know from a reliable source, namely, the 10th-century Baghdad bibliographer Ibn al-Nadīm (**XIIIc-0c**),[5] that the Muslims came into contact with the astrolabe in the mid 8th century in Harran, then a centre of Hellenistic learning.[6] Elsewhere the same source informs us that the first Muslim to actually make an astrolabe was al-Fazārī,[7] who is one of the two earliest Muslim astronomers known to us.[8] It would be nice if the Baghdad astrolabe were signed by al-Fazārī, but alas it is not. It is competently made and is surely one of the earliest astrolabes ever made by any Muslim.

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[1] For an overview of Islamic mathematical astronomy see now King & Samsó, "Islamic Astronomical Handbooks and Tables". For an overview of Islamic instrumentation see **X**.

[2] There is nothing of consequence to be added to Neugebauer, "Early History of the Astrolabe", dealing with textual transmission, except, of course, what we can write about the first surviving examples.

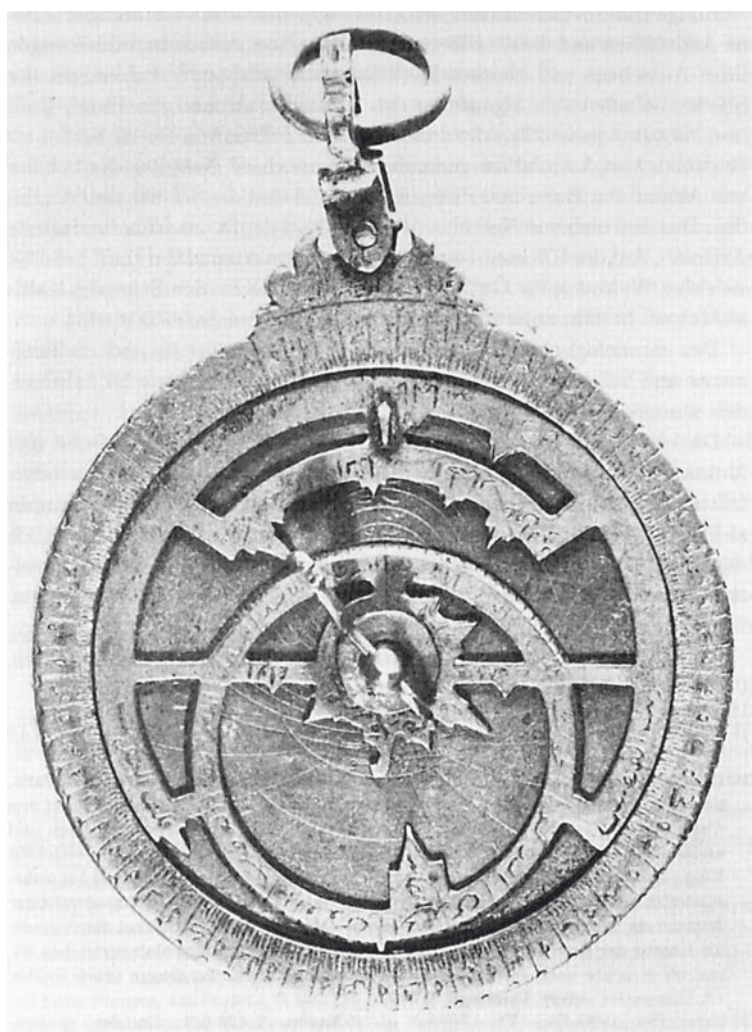
[3] On the texts see Neugebauer, "Early History of the Astrolabe". For some English translations see Gunther, *Astrolabes*, I, pp. 61-103.

[4] Dalton, "Byzantine Astrolabe", summarized in Gunther, *Astrolabes*, I, pp. 104-108 (no. 2).

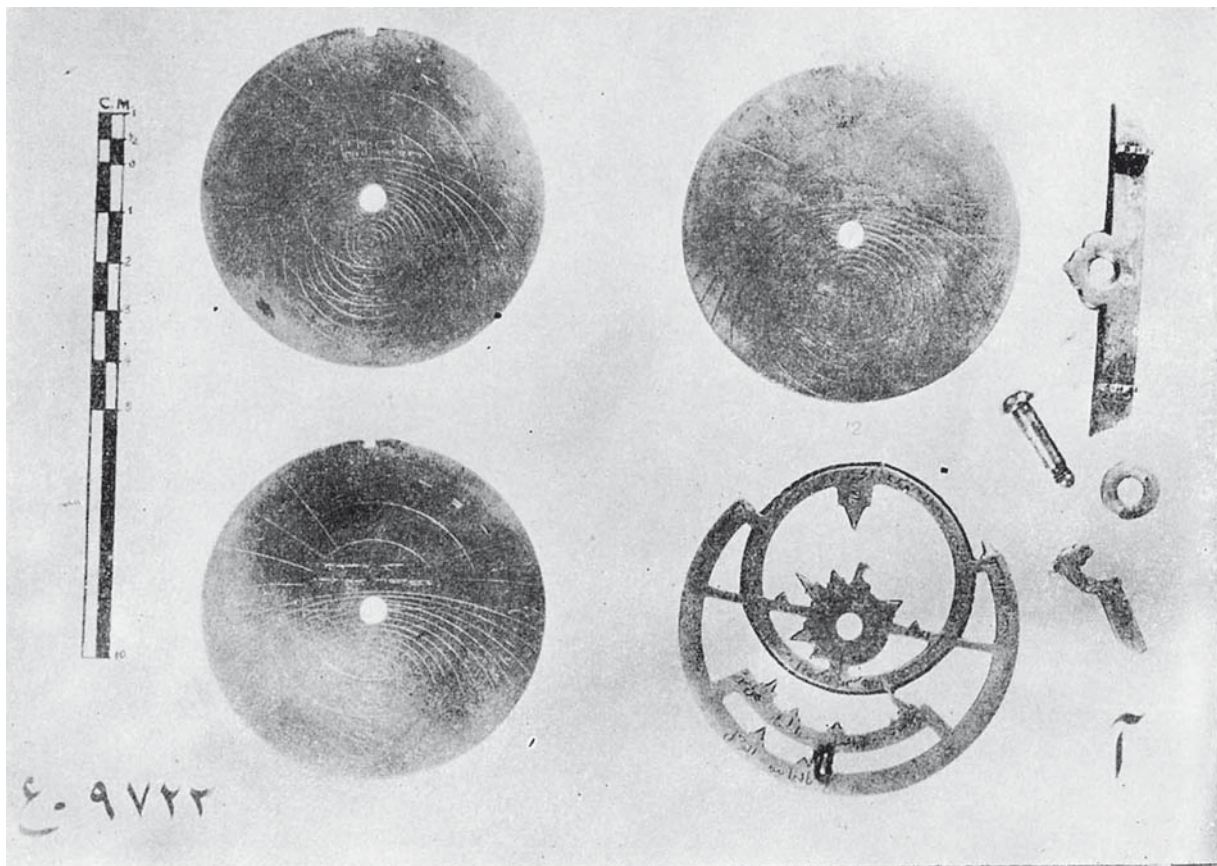
[5] On this and other sources see also King, "Origin of the Astrolabe", now in XIIIe.

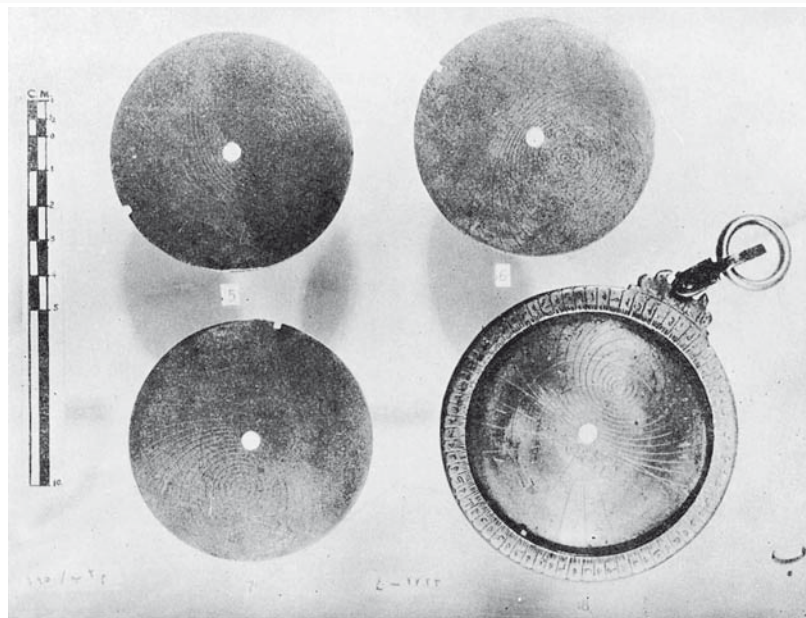
[6] See the article "Ḥarrān" by Geza Fehérvári in EI_2, which includes references to studies of the city in pre-Islamic times.

[7] Ibn al-Nadīm, *al-Fihrist*, edn., p. 273. See also **XIIIc-0c**.

[8] See the articles "al-Fazārī" and "Yaʿqūb ibn Ṭāriq" by David Pingree.

1

2

Figs. 1-4: The Baghdad astrolabe (#3702). [Photos from the 1950s courtesy of the Archaeological Museum, Baghdad.]

اللوح ـ ٢ : ثلاث صفائح لاسطرلاب مع العنكبوت • ويشاهد الى اليمين العضادة والمحور والفرس التى تثبت فيها الصفائح والعنكبوت •

3

اللوح ـ ٣ : ام الاسطرلاب وتشاهد الحجرة وثلاث صفائح منه

4

We do have several other astrolabes made in Baghdad in the late 9th and 10th centuries (see now **XIIIc**), and the piece under discussion is, appropriately, simpler and less developed than these. In fact, it represents precisely the simple type of instrument that is described in the Greek and Syriac texts on the astrolabe, and confirms what one might have suspected, namely, that the Muslims in the 8th century inherited this simple type of astrolabe.

The 1062 Byzantine astrolabe is not in the simple tradition of the earliest previously-known Islamic astrolabes, for it bears various new features, both technical and artistic,[9] although the form of its rete is in the same distinctive tradition as that of the Baghdad astrolabe. The first set of astrolabes from late-9th- and early-10th-century Baghdad bear witness to the simple design modified from the standard Byzantine design. They include:

- ❖ An undated astrolabe (#1026—**XIIIc-1.1**) and a solitary rete (#2529—**XIIIc-1.2**), the former signed by "Khafīf, the apprentice of ʿAlī ibn ʿĪsā", and the latter identical in engraving, both preserved in the Museum of the History of Science, Oxford. Khafīf seems to have been active *ca*. 875-900—see **XIIIc-0**.
- ❖ An illustration of another astrolabe by Khafīf (#4030—**XIIIc-1.3**), found in a 16th-century Italian illustration preserved in the Uffizi Gallery in Florence.
- ❖ An undated astrolabe by Aḥmad ibn Khalaf (#99—**XIIIc-2**), preserved in the Bibliothèque Nationale de France. Aḥmad ibn Khalaf seems to have made this piece *ca*. 925.
- ❖ An astrolabe by Nasṭūlus, dated 315 Hijra [= 927/28], preserved in the Dār al-Āthār al-Islāmiyya in Kuwait (#3501—**XIIIc-3.1**).

The second set, from the 10th century, bears witness to the changes and additional markings that were introduced on the instrument, mainly in the 9th century. I mention only:

- ❖ The mater of an undated astrolabe by Muḥammad ibn Shaddād (al-Baladī), formerly in Berlin, present location unknown (#1179—**XIIIc-4**). The importance of this piece is partly due to the fact that it bears three different kinds of shadow scales on the back: see **XIIa-B**.
- ❖ The mater of an imposing astrolabe by Ḥāmid ibn ʿAlī al-Wāsiṭī dated 343 H [= 954/55] (#100—**XIIIc-8.1**). The instrument was stolen from a museum in Palermo early in the 20th century and has not resurfaced.
- ❖ The spectacular astrolabe of the astronomer Ḥāmid ibn Khiḍr al-Khujandī, made in Baghdad in 374 H [= 984/5] (#111—**XIIIc-9**). It features zoomorphic and other decoration on the rete, plates for the pole and the equator and the Arctic circle (for coordinate conversion), plates for astrological purposes, an horary quadrant for latitude 33° (Baghdad), and astrological information in tabular form.

These modifications included a plate of horizons for all latitudes, several kinds of scales showing shadow-lengths corresponding to a range of solar altitudes, various kinds of trigo-

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[9] Notably, the denser altitude circles between the solstitial base circles on the plates, for improved operations with the sun, and the decorated throne. The absurd shadow scales covering the back—absurd, that is, unless they are the first "plane table" in the history of surveying—are surely a later addition.

nometric grids for facilitating operations with sines and cosines, and two kinds of markings in the form of a quadrant for finding the time from the solar altitude, either accurately for a specific latitude or approximately for all latitudes (**XIIa**). Some of these are attested already in the earliest surviving Arabic treatise on the construction and use of the astrolabe, by al-Khwārizmī (*ca*. 825); others are described in a series of treatises that have been identified during the past 20-odd years.[10] We now return to a much earlier, much simpler device.

3 The historiography of the Baghdad astrolabe

Our astrolabe came into the hands of the Iraqi astronomer ʿAbd al-Ḥalīm al-Ḥāfātī (d. 1942), whose private collection included four other astrolabes and some Arabic astronomical manuscripts.[11] This particular astrolabe, together with the other four, was donated to the Museum in the late 40s or early 50s by his son, Aḥsan al-Dīn al-Ḥāfāti.

The Baghdad astrolabe is not unknown to the literature on the history of Islamic instruments, for it was published already in 1957 by two Iraqi scholars, Bashīr Faransīs and Nāṣir al-Naqshabandī,[12] in the journal *Sumer*, the official organ of the Iraqi Ministry of Antiquities. Naqshabandī was the author of several studies on early Islamic coins.[13] Their joint article, in Arabic, described some seven astrolabes in the Museum. Alas the illustrations of our astrolabe are poor indeed, and can only with difficulty be reproduced here—see **Figs. 1-4**.[14] The descriptions are competent and adequate for the time, with a slavish commitment to record every inscription (with hundreds of corrupt entries from gazetteers), and not improved by their printers.

To put this first publication on this astrolabe in context, we should point out that in the same year, 1957, the Director of the Iraqi Museum Library, Gurgis Awad, published in *Sumer* a list of close to 200 Arabic treatises on the astrolabe.[15] Indeed, in the 1950s and early 60s there was a remarkable interest amongst Iraqi scholars in the history of Islamic science.[16]

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[10] See, for example, Charette & Schmidl, "al-Khwārizmī on Instruments"; and King, "*Quadrans Vetus*", and now **XIIa**.

[11] Fransīs & Naqshabandī, "Baghdad Astrolabes", p. 10b, and ʿAzzāwī, *History of Astronomy in Iraq*, p. 168 (both in Arabic). See *ibid*., pp. 105 (bound after p. 120), 168, 189, 233, 299, on various Arabic astronomical manuscripts also owned by al-Ḥāfātī.

[12] Faransīs & Naqshabandī, "Baghdad Astrolabes" (in Arabic), pp. 12-13 and pls. 2-3 (rete, mater and plates), and 4-5 (front and back).

[13] See, for example, his *al-Dīnār al-Islāmī fī ʻl-Mathaf al-ʿIrāqī*, Baghdad, 1953, and his articles in *Sumer* in 1948-52 and 1956. Catalogues of the medical and astronomical manuscripts in the Iraqi Museum in Baghdad have been published by his son, Usāmah Nāṣir Naqshabandī: see Sezgin, *GAS*, VI, p. 362.

[14] It is a pleasure to thank my colleague Professor Fuat Sezgin for having a set of digitalized images prepared from the *Sumer* article and placing these at my disposal, as well as Dr. Burkhard Stautz, for preparing new graphics to update those in his *Mathematisch-astronomische Darstellungen auf mittelalterlichen Instrumenten* (see n. 23).

[15] Awad, "Arabic Astrolabe Treatises". The author had no conception of Western bio-bibliographical sources on Islamic scientific literature (at that time restricted to Suter and Brockelmann), but cited a few catalogues of Western library collections, indicating that he had profited from a *riḥla*. Nevertheless, Awad's survey has never been updated or replaced.

[16] Notably, ʿAbbās al-ʿAzzāwī wrote a history of astronomy in the Islamic world, focussing on Iraq, and listing authors and their works, with occasional references to manuscripts. This (listed as *History of Astronomy in Iraq*)

In 1959 Aḥmad ibn Kamāl and the Baghdad astrolabe were listed in the inventory of Muslim instrument-makers and their works compiled by Leon A. Mayer in Jerusalem.[17] Those were the days when diligent scholars could control all publications in their chosen field! But Mayer overlooked the age of the astrolabe and the contradiction with the name of the maker.

In 1962 the Baghdad astrolabe was appropriately listed amongst the earliest surviving astrolabes by the French instrument expert, Marcel Destombes.[18] He was intent on establishing a historical context for the oldest surviving European astrolabe, which he associated with 10th-century Catalonia, a context that has been confirmed—to the annoyance of his detractors—by later investigations by myself (comparing the piece with all known—over one hundred—other early astrolabes) and Anscari Mundó (comparing the distinctive engraving with documented 10th-century inscriptions from Catalonia).[19] This extremely important object is, alas, still beyond the comprehension of the uninitiated.[20]

In 1973, Derek de Solla Price and his young colleagues at Yale University published their computerized checklist of astrolabes, devoting a one-liner to each instrument. Alas their information on this piece was deficient.[21]

The real significance of the Baghdad astrolabe was recognized only in the early 1990s when it was catalogued along with all other Islamic and European astronomical instruments from

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he published in Arabic in 1958. It is a remarkable work, not only because it is based on his researches in Baghdad libraries, but because he was completely innocent of any Western research that had been conducted on the subject over several centuries. ʿAzzāwī's collection of 3350 manuscripts went to the library of the Iraqi Museum: see Sezgin, *GAS*, VI, p. 362.

Yet another useful work, also in Arabic, is on Islamic cartography by Ibrāhīm Shawkat, published in 1962 in a journal of the teacher-training college at Baghdad.

I have not yet been able to consult another work in Arabic by Shawkat published in 1970, this time dealing with the astrolabe ("*al-Asṭurlāb*"). The Arabic title translates: "The astrolabe: methods and principles of its engraving and construction", so that presumably it deals with the theory and construction of the instrument. George Saliba ("Astrolabe of Khafīf", p. 115, n. 9) mentions that Shawkat here states that the astrolabes of Khafīf are the oldest surviving ones known to us. Shawkat was surely familiar with the tiny Baghdad astrolabe, but probably accepted the dating of Faransīs and Naqswhabandī to the 10th century.

In Baghdad in 1968 there was published an encyclopaedia of the history of the Arabic script, entitled *Atlas of Arabic Calligraphy (Muṣawwar al-khaṭṭ al-ʿarabī*), authored by Nājī Zayn al-Dīn, a large and most useful volume illustrating dated specimens of calligraphy and engraving. My copy was liberated by a student at the end of a seminar at New York University in the early 1980s, and I have not seen another copy of this splendid book since.

Also in those days the Baghdad publishing house al-Muthannā published a substantial number of reprints of editions of medieval Arabic scientific works, pirated from various 19th- and 20th-century Orientalist works. For example, they reprinted W. Ramsey Wright's 1934 facsimile edition and translation of al-Bīrūnī's introduction to astronomy and astrology, and C. A. Nallino's edition of the astronomical handbook of al-Battānī (one the one volume with the Arabic text, the two volumes with Nallino's Latin translation and commentary were deemed superfluous, even though—or maybe because—they contained all the tables).

[17] Mayer, *Islamic Astrolabists*, supp., p. 294.

[18] Destombes, "Astrolabe carolingien", p. 12, dating the piece to the second half of the 10th century, by analogy with the rete of Aḥmad ibn Khalaf (#99—1.2.3).

[19] See our respective contributions to Stevens *et al*., *The Oldest Latin Astrolabe*.

[20] A hapless description recently published in *Paris IMA 2000 Exhibition Catalogue*, p. 242 (no. 245), undoes the work of several specialists, daring to even suggest the possibilities of an origin in Italy, Sicily or Northern France and a post-12th-century provenance, and virtually dismissing the instrument as "atypique".

[21] Price *et al*., *Instrument Checklist*, p. 29, lists this instrument with its location and the name of Aḥmad ibn Kamāl, omitting the diameter and any dating.

before *ca*. 1500.[22] In the mid 1990s the Baghdad astrolabe featured prominently in various writings by Burkhard Stautz, who was the first to recognize a very remarkable feature of the star-positions on the rete and who used the piece appropriately to demonstrate the form in which the astrolabe was transmitted to the Muslims.[23]

Our concern here is first with the article by Faransīs and Naqshabandī. They recognized the early provenance of this particular Baghdad astrolabe, assigning it to the 10th century on the strength of some *kūfī* inscriptions, and they asserted that the limbus and rete and were later replacements, both fashioned (they used the word *ṣanaʿahumā*, indicating a dual object) by the man whose name is engraved on the front of the throne. The reader should be aware that even at the end of the 20th century, scholars who on a local level were taken as experts on instruments, have been dumbfounded by artefacts with two layers of inscriptions. In fact, the different layers can usually each tell us something, often about the subsequent fate of the original piece.[24]

I am going to suggest that, in this case, the entire astrolabe is very early Islamic, 8th century, and that the rete has been reworked, probably in the 18th or 19th century. Alas I cannot offer proof in the standard form of a complete set of photos with blow-ups of important details. I have only poor quality photos of the front and back, diameter 3.5 cm, yet worse photocopies of the mater and plates, as well as the description by Faransīs and Naqshabandī (hereafter, F&N).

4 The description of Faransīs and Naqshabandī and its problems

F&N state, on the evidence of the *kūfī* engraving, that the mater and plates are from the 10th century. But it should be pointed out that they had never seen a 9th- or a 10th-century astrolabe, and they present no comparative epigraphic evidence for their assertion. Further, they do not comment on the unhappy Arabic of the inscriptions in the plates (see **2.5** and **3.13**).

F&N assert that the limbus of the mater and the rete are "recent" (*ḥadīth*), attributing both to Aḥmad ibn Kamāl (*ṣanaʿahumā*), whose name they read engraved on the throne. There is no other inscription on the throne beyond this name.

Now the limbus *cannot* be a replacement, for there is not a trace of any rivets on the front of the limbus or on the back of the mater. Besides the numbers engraved on the scales on the front of the limbus and the back of the mater are in the same *kūfī* hand. I have no doubt then, that the limbus, apparently one piece with the throne and the mater, is original.

Also the rete itself is original. It is the only the star-names that are a later addition. Unfor-

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[22] Alas, this catalogue (see **XVIII**) remains unpublished, partly because it is not complete, partly because of the difficulties in obtaining photos, partly because funding was exhausted, but also because, apart from a few *aficionado*s, there is a serious lack of interest in medieval instruments. In fact, at the time of writing, not a single voice has reacted to the table of contents of the catalogue that was put on the Internet some years ago!

[23] Stautz, "Die früheste Formgebung der Astrolabien", and *idem*, *Mathematisch-astronomische Darstellungen auf mittelalterlichen Instrumenten*, pp. 41-43 (no. A2), and 179-181 (graphics), also *Munich Astrolabe Catalogue*, pp. 14, and 16-17.

[24] The Destombes astrolabe is the best example (see nn. 19-20), but there are several others one could mention, including one with five layers of inscriptions in three languages: see King, "Medieval Spanish Astrolabe", now in **XV**.

tunately, F&N's rendering of the star-names is very unreliable, which is particularly surprisingly because Naqshabandī was a specialist in inscriptions on early Islamic coins. They record 20 names, one of which is not a name of any astrolabe-star, another is not on the rete anyway, and three of their names are repeated.[25] They would have done well to compare the names they were copying with those on the other astrolabes they published. Fortunately, even though they are not all visible on the available photos, the star-names in *naskhī* can be reconstructed (see **2.4**). In fact, using these, we can also reconstruct the original names (see **3.5**).

5 The problem of the engraving in *naskhī* script

Alas, the available photos, two published by F&N and published again here from copies, and two published by F&N that are published again here from photos made from the some original negatives, are of such poor quality that they are inadequate to confirm or refute some of the assertions made by F&N.

Most serious is the problem of the inscription on the throne. The most I can confirm is "Aḥmad ibn (son of) ——[l]", the final "l" (Arabic *lām*) of the second name being visible. I could also be persuaded that the name Aḥmad might be preceded by the word *yā*, the vocative particle, although the "y" (*yāʾ*) lacks the two dots, and such an inscription would make no sense anyway, because the invocation would have to be to the deity or to a religious personality. But there is still hope. For no common Arabic names that end in "l" come to mind other than Kamāl, or Kāmil, and Jamāl, or perhaps Bilāl. (There is not enough space for a name in the form of a *nomen professionis*, which would necessarily be introduced by the distinctive definite article *al-*.) So I am inclined to give F&N the benefit of the doubt, and accept Kamāl as the name of Aḥmad's father. Now names of the form Kamāl al-Dīn, "the Perfection of the Religion [*sc*. Islam]", or Jamāl al-Dīn, "the Beauty of the Religion", are attested from the late 9th and especially the 10th century but they were not generally shortened to Kamāl, *etc*., before the Timurid and Ottoman period.[26] Note that the astrolabist of Ulugh Beg in early-15th-century Samarqand was known as, and signed his instruments as, Jalāl al-Asṭurlābī (see **XIVd-0**).

It should be pointed out that the presence in *naskhī* inscriptions is not in itself necessarily an indication of great age. However, the *naskhī* on this astrolabe is very late. The two oldest signed Islamic astrolabes have inscriptions that will surely surprise specialists in engraving:

- ❖ One in Oxford (#1026—**XIIIc-1.1**), datable *ca*. 875-900, is signed in *a round* naskhī *script*. On the back of the throne we read: "Khafīf, *ghulām* of ʿAlī ibn ʿĪsā", and on the front: "by order of (*bi-rasm*) Aḥmad al-Munajjim ("the astronomer/astrologer" or "the member of the al-Munajjim family") al-Sinjārī". Significant is the lack of a verb "constructed by".

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[25] They propose, within the ecliptic:- (1) *fakka*—(2) *al-ḥawwāʾ*—(3) *al-wāqiʿ*—(4) *ridf*—(5) *al-ʿawwāʾ* [*sic*; not an astrolabe-star!]—(6) *al-dabarān* [*sic*; should not be inside the ecliptic!]—(7) *al-rāʿī* [no such astrolabe star! *sic* for *al-rāmiḥ*]—(8) *kaff al-khaḍīb*; on the ecliptic:- (9) *al-ṭāʾir*; and outside the ecliptic:- (10) *qalb al-asad*—(11) *al-shaʾā*[*miya*]—(12) *ʿayn al-thawr*—(13) *qalb al-ʿaqrab*—(14) *al-yamāniya*—(15) *al-rijl*—(16) *dhanab al-qayṭus*—(17) *qalb al-asad* [repeated]—(18) *al-shā*[*miya*] [repeated]—(19) *al-jabbār*—(20) *ʿayn al-thawr* [repeated].

[26] The best sources known to me on Islamic names are Schimmel, *Islamic Names*, and the article "Ism" [= names] in *EI*$_2$, by the editors.

- ❖ The other in Paris (#99—**XIIIc-2**), datable *ca*. 925, is signed in *kūfī* script: "Made by (*ṣanaʿahu*) Aḥmad ibn Khalaf for Jaʿfar son of al-Muktafī bi-llāh".

Now, an owner might put his name on the throne of an astrolabe without further words, especially in the late period: see, for example, **Fig. XIVg-1**.

The rete shows no apparent signs of having been reworked. It would have been nice to be able to identify part of a *kūfī* star-name that had not been obliterated. It is almost as if the rete had been devoid of star-names. But there is evidence that these star-names in *naskhī* were at least inspired by, if not copied from, a set of 8th- or 9th-century star-names (see **3.5-9**).

Finally, I cannot confirm that the *naskhī* script of that inscription is the same as the engraving of the star-names on the rete, though F&N stated that it was.

Thus it seems highly likely, but it is not certain, that this Aḥmad ibn Kamāl was a person who came to own this astrolabe, probably in the 18th or 19th century. He, or another, felt a need to engrave the star-names in *naskhī* script.

2 Description of the Baghdad astrolabe

> "And he arose, and stretching forth his hand, took out a handkerchief and opened it; and lo, there was in it an Astrolabe consisting of seven plates." From the story of the tailor in *The Thousand and One Nights*, cited in Gunther, *Astrolabes of the World*, I, p. 173, quoting Edward Lane's 1839-41 or 1859 edn., I, p. 372.

1 Basic information

The astrolabe is numbered 9723 in the collection of the Dār al-Āthār (Archaeological Museum), Baghdad, and 3702 in the International Instrument Checklist.[27] The instrument is in brass and has a diameter of 8.5 cm.

2 The two layers of inscriptions

The workmanship is simple but not crude, the script a neat *kūfī* (mater and plates) and an inelegant but legible *naskhī* (rete), and there are one or two features which indicate that the maker was not completely in control of his craft. It is most likely that the plates are original Abbasid because the script is *kūfī*, although the style of the inscriptions—see below—is poor Arabic and more typical of Ottoman Turkey that Abbasid Iraq. Certainly, under scrutiny of a magnifying glass applied to poor-quality photographs on which the astrolabe has a diameter of 35 mm, the mater and rete give no indication of having been reworked. For the following description, I have been forced to rely on the publication and on the photos of the front and back.

The inscription that can be accepted as "Aḥmad ibn Kamāl" is engraved as low as possible on the throne, because presumably the shackle was already in place and not much room was available.

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[27] See n. 21 above.

3 The throne and limbus

The throne is raised and awkward in design, being non-symmetrical about the vertical, but the "vertical axis" itself is not properly vertical anyway. There are basically two lobes on each side with a small hole on the outer lobe on the right. There is a larger hole on each side within the larger "lobe", in the Abbasid tradition, but these "holes" are open at the outer edges. The suspensory apparatus attached to a smaller hole at the middle is a primitive shackle with swivel and a circular ring.

The scale on the limbus is crudely divided for each 5° with subdivisions for each 1° and labelled for each 5° clockwise to 90° in each quadrant (without tens and hundreds) (there seem to be problems with the labelling of some of the 5°-intervals in the lower left quadrant), the numerals being written in *kūfī*, and the rim of the mater unusually wide. All numbers here and elsewhere are in the Arabic alphanumerical (*abjad*) notation.[28] The inside of the mater has a peg at the bottom to hold the plates and is marked—see below.

4 The rete

The rete is simple and not decorated. The inscriptions are in *naskhī*. The equinoctial bar is rectilinear and there is a broad equatorial frame. The scale on the ecliptic ring bears unlabelled disvisions for each 6° and the names of the zodiacal signs are:

al-ḥamal—al-thawr—al-jawzāʾ—al-saraṭān—al-asad—al-sunbula—al-mīzān—
al-ʿaqrab—al-qaws—al-jady—al-dalw—al-hūt

These are standard, and just what we would expect from an engraver in the Ottoman period. Pisces (*al-ḥūt*) is invariably labelled *al-samaka* on early Abbasid astrolabes (see further **3.16** and also **XIIIc-3.1-3**, **2**, **3.1**, **6**, and **8.2**).

The form of the pointers is dagger-shaped, typical of early Abbasid retes (see **3.4**). In all, 17 stars are named, although one name does not relate to a pointer. Also, one pointer is not named at all. Thus there are actually 17 pointers, with 16 of them named.

If we drop three of the 20 names F&N record that are repeated, we are left with 17 stars-names, of which one—*dhanab al-qayṭus*—does not relate to an original star-pointer. But there is one pointer without any name, so for our investigation of the astrolabe we are back to 17 real pointers. We now order these by increasing right ascension measured from the vernal equinox. Those names that are clearly visible and legible on the available photo are written in bold font. The stars that are named are the following:

1	[*raʾs al-ghūl*]	illegible, not named by F&N, though perhaps this—by a considerable stretching of the imagination—is their *al-dabarān*
2	**ʿayn al-thawr**	F&N have this twice, as well as the alternative name *al-dabarān*
3	[al-*ʿayyūq*]	name illegible—F&N have *al-ʿawwāʾ*, which may refer to this pointer

[28] See Destombes, "Chiffres coufiques".

4	**al-rijl**	
5	**al-jabbār**	
6	**al-yamāniya**	
7	**al-shaʾām**[*iya*]	missing last part of name
8	-	unnamed minuscule pointer
9	*qalb al-asad*	not legible, named twice by F&N
10	**al-rāmiḥ**	this is F&N's *al-rā'ī*
11	*fakka*	name not visible, named by F&N
12	**qalb al-ʿaqrab**	
13	**al-ḥawwāʾ**	**shaped like a bird's head**
14	**al-ṭāʾir**	
15	[*al-wā*]**qiʿ**	only last part of name visible, *al-wāqiʿ* named by F&N
16	*rid***f**	name not visible beyond final *fā'*, *ridf* named by F&N
X	**dhanab al-qayṭus**	**no pointer**
17	*kaff al-khaḍīb*	name not visible, named by F&N

See **3.8-9** on the original names on the rete.

5 The mater and plates

The mater and three plates bear altitude circles for each 6°. There are no azimuth circles. The plates serve the seven climates (*iqlīm al-awwal ʿarḍuhu yw*, *etc*.), their latitudes being given as:

mater	1	16°
1a	2	24
1b	3	30
2a	4	36
2b	5	41
3a	6	45
3b	7	48

There are curves for the seasonal hours below the horizon. The inscriptions are in elegant *kūfī* script. There are holes at the bottom of the plates to fit onto the peg on the mater.

6 The back

The back has two altitude scales divided and labelled for each 5° with sub-divisions for each 1° in the upper half. The concentric circles near the rim on the lower half have not been engraved further. But for the base diameters, the back is otherwise empty.

7 The alidade

The alidade is rectilinear with a lobed design around the middle. It just reaches the inner circle of the degree scale and so may not be "original". The sighting vanes have three indents along the top.

3 Commentary

1 The inscription on the throne

As noted already (**1.5**), I can accept F&N's reading of "Aḥmad ibn Kamāl" on the front of the throne and all of the implications: namely, that this cannot be the name of the maker, that it may be the name of an owner, and that perhaps it is the name of the person who engraved the star-names on the rete.

2 The size of the astrolabe

The diameter of the astrolabe (8.5 cm, hereafter ∂) is such that the piece could only really serve decorative purposes. Add to that: it cannot be used at the latitude of Baghdad anyway (see **3.14**). I suspect that there were astrolabes with Greek inscriptions made in this size (8.5 cm), this being the smallest. Philoponos mentions that the smallest astrolabes are sextile, that is, they have altitude circles for each 6° of argument. However, the Brescia Byantine astrolabe (#2—1.1.1), which is also sextile, albeit with tertile markings between the solstitial circles, has a diameter of 38.0 cm.

There is one very early Abbasid astrolabe with the same diameter, possibly of the same type and from the same milieu, in a private collection (see **4**). And there is another (#4180—**XIIIc-5**) by al-Muḥsin ibn Muḥammad al-Ṭabīb, slightly larger, with diameter 8.9 cm. Otherwise the earliest Eastern Islamic astrolabes are larger:

#1026—**XIIIc-1.1**—Khafīf	11.2 cm
#99—**XIIIc-2**—Aḥmad ibn Khalaf	12.9 (≈ 1.5 ∂)
#3501—**XIIIc-3.1**—Nasṭūlus	17.3 (≈ 2 ∂)
#1130—**XIIIc-3.2**—Nasṭūlus (mater)	13.0 (≈ 1.5 ∂)
#101—**XIIIc-6**—unsigned	16.0
#4022—**XIIIc-7**—unsigned	11.7
#100—**XIIIc-8.1**—Ḥāmid ibn ʿAlī	15.4
#3713—**XIIIc-8.2**—Ḥāmid ibn ʿAlī	11.0
#111—**XIIIc-9**—Ḥāmid ibn Khiḍr al-Khujandī	15.1

3 The design of the throne

The throne is of the same kind as various Islamic astrolabes from before *ca*. 950—see, for example, various illustrations in **XIIIc**.

I have given my reasons above (**2.5**) for supposing that the rim is original, indeed, that it appears to be one piece with the back and throne. In passing we note that the limbus of the Oxford astrolabe of Khafīf (#1026—**XIIIc-1.1**) seems be riveted to the back (one rivet is visible at 60°), but that the limbus of the Paris astrolabe of Aḥmad ibn Khalaf appears to be one piece

with the back and throne. On the Kuwait astrolabe of Nasṭūlus (#3501—**XIIIc-3.1**), the throne and rim are cast as one and to this the back is riveted in several places.

4 The design of the rete

The rete resembles most closely that of the 1062 Byzantine astrolabe (#2—see **Figs. 5** and **XIIIa-4.1**), and, amongst Islamic pieces, those of Khafīf (#1062—**XIIIc-1.1** and #2529—**XIIIc-1.2**) and Aḥmad ibn Khalaf (#99—**XIIIc-2**). It is clearly simpler and indeed cruder than these, suggesting an earlier provenance.

5 The selection of stars

The retes of the Byzantine astrolabe and various early Islamic astrolabes enable us to recognize that the *naskhī* inscriptions for three star-pointers are incorrect, at least from the point of view of an Abbasid astrolabe, and represent wishful thinking on the part of an Ottoman astrolabist. These are:

13	*al-ḥawwāʾ*	shaped like a bird's head
15	[*al-wā*]*qiʿ*	only last part of name visible, named by F&N
16	*ridf*	name not visible beyond final *fāʾ*, *ridf* named by F&N

These are stars that our Ottoman engraver chose to re-label because his designations seemed more reasonable. The correct names on the original rete would have been as follows. The justification follows below.

13	*al-wāqiʿ*	shaped like a bird's head, name applied to pointer 15
15	*ridf*	name applied to pointer 16
16	[*mankib al-faras*]	not named, pointer marked *ridf*; the name—meaning "shoulder of the horse (Pegasus)"—appears on all Abbasid retes

Now David Pingree has recently published a Byzantine list of 19 stars dated 908, which somebody was obviously intending to use for constructing an astrolabe.[29] The coordinates given are confused and one can only hope that he did not actually make an astrolabe based on such coordinates. The Persian Sergius who made the Byzantine astrolabe of 1062 included 14 of these 19 stars.

The Byzantine list enables us to identify the small, unnamed pointer next to that for Regulus. Again the justification follows below. The star served is:

8	*fard / al-fard / fard al-shujāʿ / ʿunuq al-shujāʿ / al-munīr min al-shujāʿ*	α Hydrae, various Arabic names, of which *ʿunuq* or *ʿunq* corresponds to the Greek equivalent of "neck of Hydra" (B8)

[29] Pingree, "Greek Astrolabe Stars".
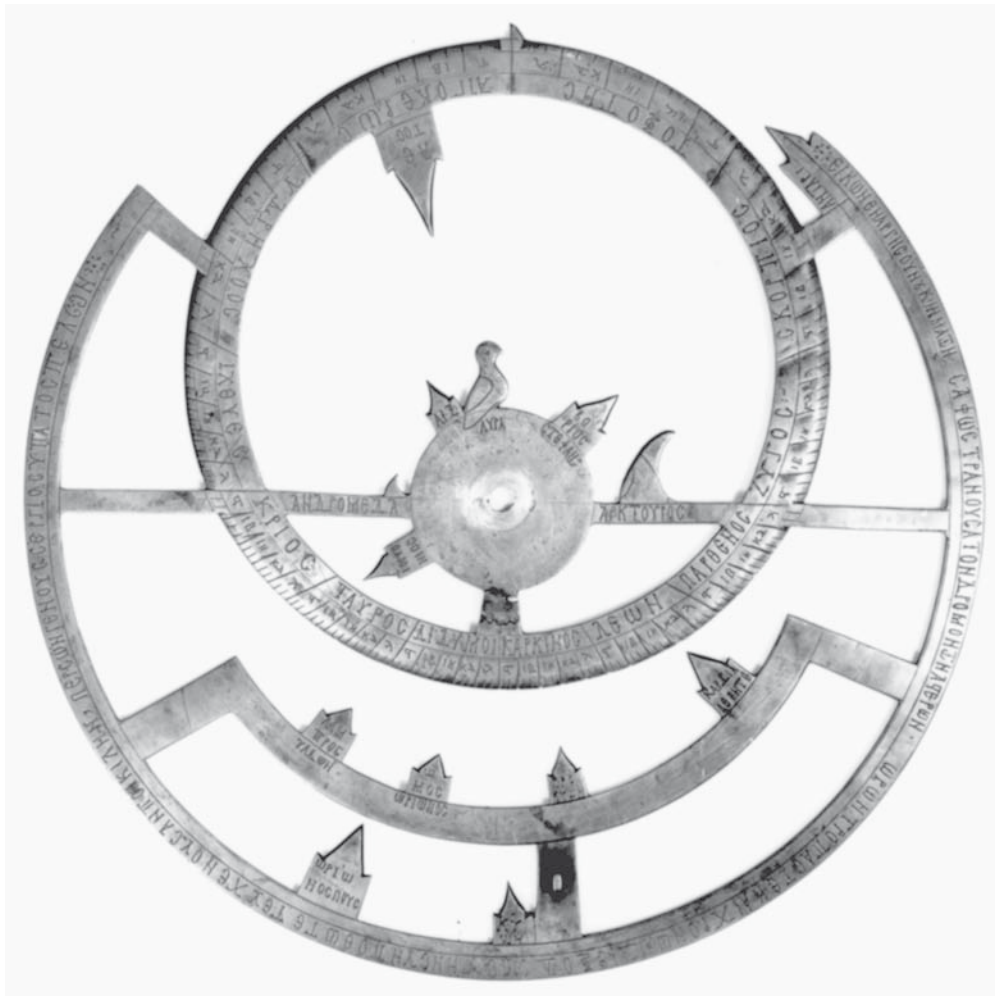
Fig. 5: The rete of the Brescia astrolabe (#2). No other Islamic astrolabe beyond the Baghdad piece (#3702) bears such a strong resemblance to this Byzantine model. [Courtesy of of the Museo dell'Età Christiana, Brescia.]

It is not clear which name would have originally been assigned to this pointer. It does not appear on surviving astrolabes until the unsigned piece, #101—1.2.7, which is perhaps late 10th-century, where it is labelled *ʿunuq al-shujāʿ*, "the neck of the water-snake (Hydra)", and #111—**XIIIc-9**, by al-Khujandī, dated 374 H [= 984/85], on which we find both the neck and the head: *ʿunuq al-shujāʿ* and *raʾs al-shujāʿ*.

We can now list the 17 stars of the original rete with their numbers in the Byzantine list (B) and Paul Kunitzsch's lists of Arabic and Latin astrolabe stars (A/L),[30] together with their modern designations.

[30] See, respectively, Kunitzsch, "Al-Ṣūfī and the Astrolabe Stars", pp. 158-161, and *idem*, *Arabische Sternnamen in Europa*, pp. 59-96.

1	*raʾs al-ghūl*	B1	A9/L14	β Persei / Algol
2	*ʿayn al-thawr*	2	24/18	α Tauri / Aldebaran
3	*al-ʿayyūq*	3	10/20	α Aurigae / Capella
4	*al-rijl*	4	37/19	β Orionis / Rigel
5	*al-jabbār*	5	36/22	α Orionis / Betelgeuze
6	*al-yamāniya*	6	39/23	α Canis maioris / Sirius
7	*al-shaʾāmiya*	7	40/25	α Canis minoris / Procyon
8	[*ʿunuq al-shujāʿ* (?)]	8	42/29	α Hydrae / Alfard
9	*qalb al-asad*	9	26/30	α Leonis / Regulus
10	*al-rāmiḥ*	12	1/41	α Bootis / Arcturus
11	*fakka*	13	2/45	α Coronae borealis / Alfeca
12	*qalb al-ʿaqrab*	14	30/48	α Scorpii / Antares
13	*al-wāqiʿ*	15	4/53	α Lyrae / Vega
14	*al-ṭāʾir*	16	13/54	α Aquilae / Altair
15	*ridf*	17	6/56	α Cygni / Deneb
16	[*mankib al-faras*]	18	17/62	β Pegasi / Scheat
17	*kaff al-khaḍīb*	(19)	7/1	β Cassiopeiae / Kaff; B19 actually lists α Andromedae / Alpheratz (A15/L1)

In passing we note that the two stars from the Byzantine list missing from the Baghdad astrolabe are B10: β Leonis / Denebola and B11: α Virginis / Spica. These two are also missing from the Byzantine astrolabe, as are B8: α Hydrae / Alfard (pointer would be too short), B17: α Cygni / Deneb and B18: β Pegasi / Scheat. More important, perhaps, and not mentioned by Pingree, is the fact that Philoponus (*ca*. 625) in his astrolabe treatise mentions that the rete should bear 17 or more stars:[31] Pingree's list and the Byzantine astrolabe have 19 and the Baghdad astrolabe has 17. We can assert that *the Baghdad astrolabe bears witness to the earliest known set of astrolabe stars*.

6 The use of the bird on the pointer for Vega

This bird is not found on any other early Islamic astrolabe, but (for reasons that are not clear) it is found on the rete of the 1062 Byzantine astrolabe (#2—1.1.1) (**Fig. 5**). It does reappear on the rete of a geared astrolabe made in Isfahan in 618 Hijra [= 1223/24] by Muḥammad ibn Abī Bakr al-Rāshidī al-Ibarī (#5—1.4.6a) (see **Fig. XVII-1.4**),[32] on a zoomorphic rete of an astrolabe by ʿAbd al-Karīm al-Miṣrī (#104—1.5.6b) (see **Fig. XVII-1.7**),[33] as well as on a

[31] Gunther, *Astrolabes*, I, p. 71, also recorded in Neugebauer, "Early History of the Astrolabe", p. 249, and Stautz, "Die früheste Formgebung der Astrolabien", p. 318.

[32] Gunther, *Astrolabes*, I, pp. 118-120 (no. 5).

[33] *Ibid*., I, pp. 236-237 (no. 104).

Catalan astrolabe from *ca*. 1300 (#162) (see **Fig. XVII-3.1**).[34]

In **XVII** I have argued that the quatrefoil, which appears on the magnificent astrolabe of al-Khujandī (#111—**XIIIc-9**), constructed in Baghdad in 374 Hijra [= 984/85],[35] on an unsigned rete made in Isfahan *ca*. 1100 (#3—**XIIIc-A1**),[36] on the geared astrolabe from Isfahan (#5—see **Fig. XVII-1.4**), and on a series of later Eastern Islamic pieces, as well as on the same Catalan astrolabe (#162) from *ca*. 1300, is also probably a design that was found on some Byzantine astrolabes that became available to Muslim craftsmen.[37]

7 The positions of the star-pointers

Burkhard Stautz has established that the positions of the stars correspond to the actual positions of the stars *ca*. 500. This apparent anomaly can be explained by the fact that they were surely calculated for *ca*. 700 using the Ptolemaic coordinates (for *ca*. 125) adjusted for the motion of precession using the Ptolemaic parameter, 1° per 100 years, which is too small.[38] A better value for precession derived in Baghdad in the 9th century was 1° per $66^2/_3$ years; still better was the value derived by Ibn Yūnus in Cairo *ca*. 990, namely, 1° per $70^1/_4$ years.[39]

8 The names of the stars

If this was indeed an 8th-century astrolabe with original Arabic inscriptions and star-names that inspired Aḥmad ibn Kamāl or somebody else to re-engrave the star-names in *naskhī*, then the question arises: how did the original maker know the names of the stars? Most of them are, in fact, pre-Islamic Arabic names,[40] as, for example:

al-ʿayyūq—(al-shiʿrā) al-yamāniya—(al-shiʿrā) al-shaʾāmiya—(al-simāk) al-rāmiḥ—al-fakka—(al-nasr) al-wāqiʿ—(al-nasr) al-ṭāʾir—ridf—kaff al-khaḍīb

However, a few relate to the Greek constellation figures:

ʿayn (eye) of al-*thawr* (Taurus)—*al-jabbār* (for Orion)—*qalb* (heart) of *al-asad* (Leo) —*qalb* of *al-ʿaqrab* (Scorpio)—[*mankib*] (shoulder) of [*al-faras*] (Pegasus)

The name for Orion merits special attention (see **3.9**), and of the three zoomorphic signs, all bear Arabic names corresponding to the Greek constellations (Taurus, Leo, Scorpio), but these are names from the indigenous Arabic tradition of the zodiac.[41] Likewise, *al-faras* (horse) for

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[34] Gunther, *Astrolabes*, II, pp. 306-309 (no. 162), and the more detailed discussion in King & Maier, "London Catalan Astrolabe", especially pp. 682-683.

[35] Described in King, "Kuwait Astrolabes", pp. 80, 82-89; see now **XIIIc-3.1**.

[36] This is a replacement rete on the astrolabe made in 374 Hijra [= 984/5] by Aḥmad and Muḥammad, sons of Ibrāhīm al-Iṣfahānī (#3—1.2.11), illustrated in Gunther, *Astrolabes*, I, pp. 114-116 (no. 3). It can be dated *ca*. 1100 by virtue of the star-positions, and it has a quatrefoil in the Khujandī tradition. See now **XIIIc-10**.

[37] King, *The Ciphers of the Monks*, pp. 380-390.

[38] See n. 23.

[39] See the article "Minṭaḳa" [= ecliptic] by Paul Kunitzsch in EI_2, and King & Samsó, "Islamic Astronomical Handbooks and Tables", pp. 37-38.

[40] On these see Kunitzsch, *Sternnomenklatur*, nos. 47, 289b, 290b, 270, 85, 195a, 194a, 248, 136a-c, respectively.

[41] On the names of the signs in Arabic see *ibid*., pp. 21-25, and more recently, the same author's article "Minṭaḳat al-burūdj" [= ecliptic and zodiac] in EI_2.

what was Pegasus to the Greeks is indigenous Arabic.[42] In short, it does not seem unreasonable to suppose that all of these names were current at least in Ḥarrān at a time even *before* the first Arabic translation of the *Almagest*.

Of course we cannot be certain that Aḥmad ibn Kamāl re-engraved precisely the same names as he found on the rete. He may, for example, have preferred *ʿayn al-thawr* to the original Arabic *al-dabarān*, found on other early Abbasid astrolabes (see **XIIIc**). Certainly, he has added the name *dhanab* (tail) of *al-qayṭus* (Cetus), for this would not have been on the original astrolabe because there is no pointer for it.

9 The name of Orion

The use of the term *al-jabbār* for the Greek constellation of Orion is significant. Paul Kunitzsch, the leading authority on star-names, has written that *al-jabbār*, "the giant", appears only in or after ("*erscheint nur in bzw. seit*") the time of the Arabic translations of Ptolemy's *Almagest*,[43] which occurred perhaps first *ca*. 800 (not extant) and then *ca*. 825 (extant). The Arab / Arabic name for this constellation was *al-jawzāʾ*, "the twins". Perhaps Kunitzsch's statement needs to be modified, for maybe the first Muslim to investigate a Greek astrolabe, long before any *Almagest* translations were undertaken, posed the question: "Who was Orion?", and received a reply to the effect that "he was a big guy". In the translation of al-Ḥajjāj (827/8) the text translates "constellation of *al-jabbār*, which is *al-jawzāʾ*", whereas the later version of Isḥāq ibn Ḥunayn (*ca*. 885) translates: "constellation of Orion, which is *al-jabbār*, also known as *al-jawzāʾ*".[44]

On other known early Islamic astrolabes *al-jabbār* is attested only on the Paris astrolabe of Aḥmad ibn Khalaf *ca*. 925 (#99—**XIIIc-2**), which could derive from an Arabic *Almagest* designation.[45] On other Islamic astrolabes in general term *al-jabbār* is found only, but most appropriately, on the universal plate on the back of a highly decorative astrolabe by al-Sahl al-Nīsābūrī (#137—**XIVb-2**), datable between 1180 and 1280, and now in Nuremberg. This piece, beautifully decorated with circus figures, is not without its problems, in that the star-positions on the rete and on the universal grid on the back are for epoch *ca*. 500, or rather *ca*. 750, using Ptolemaic star-positions and precession.[46] In passing, we note that the Baghdad and Nuremberg instruments are the only known Islamic astrolabes with this curious feature. It is, of course, easier to explain on an 8th-century astrolabe than on one from the 12th or 13th century.

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[42] See Kunitzsch, *Sternnomenklatur*, no. 89 (*al-faras al-kāmil / al-tāmm*).

[43] Kunitzsch, *Sternnomenklatur*, pp. 73 (no. 140) and 105 (no. 266). The Arabic *jabbār* was perhaps inspired by the Syriac *gabbārā*: see Paul Kunitzsch in the *EI*$_2$ article "Minṭaḳat al-burūdj", esp. p. 83a.

[44] Kunitzsch, *Sternkatalog des Almagest*, I, pp. 226 and 126 and 130b (al-Ḥajjāj), and 227 and 127 and 131 (Isḥāq).

[45] See also Kunitzsch, *Arabische Sternnamen in Europa*, pp. 60 and 72 (*ad* no. 22).

[46] King, "Nuremberg Astrolabes", II, pp. 570-574 (no. 1.71); and Stautz, *Mathematisch-astronomische Darstellungen auf mittelalterlichen Instrumenten*, pp. 66-67 (no. SA1) and 205-207. See now **XIVb-2**.

10 The simplicity of the marking on the plates

There are only altitude circles and curves for the seasonal hours on the plates. The fact that there are no azimuth circles is significant, for these appear to have been introduced only in the middle of the first half of the 9th century.[47]

11 The use of the climates on the plates

The seven climates of Antiquity are defined in terms of the length of longest daylight. At the middles of the climates, the longest day is 13 hours, $13^1/_2$, 14, ... , 16, and at the beginnings of the climates $12^3/_4$, $13^1/_4$, *etc*., so that at the end of the 7th it is $16^1/_4$ hours (see **Fig. XVI-2.1**). The importance of the climates in the history of medieval instrumentation has only recently been recognized.[48] We note that *this is the only surviving early Eastern Islamic astrolabe with plates for the seven climates*. In passing, it should be recalled that the earliest Greek astrolabes had this feature, although the 1062 Byzantine astrolabe has plates for three specific latitudes (of which all three are actually for two climates), and that the earliest known Western Islamic astrolabe (#4024—1.3.1—see **Figs. XIIIa-9.2a-b**), illustrated in an 11th-century Latin manuscript, has this feature,[49] as do some of the earliest European astrolabes (#161—6.1.2). We note also the astrolabe with inlaid silver decoration mentioned in the *1001 Nights* is said to be fitted with seven plates; these are probably to be interpreted as seven surfaces (three plates and the mater) for the climates.[50] However, although we have several examples of astrolabes with silver inlay from Mamluk Egypt, where the tales were compiled, no medieval Egyptian astrolabes are known to have plates for the climates.

As I have shown elsewhere, most Muslim instrument-makers from the 9th century onwards achieved a kind of compromise between remaining loyal to the climates of Antiquity and hence attaining a kind of "universality" and ensuring that their instruments were equipped for certain specific latitudes of particular personal interest.[51] Thus, for example, on the Oxford astrolabe of Khafīf (#1026—**XIIIc-1.1**) we find plates serving latitudes 33°, 34°, 35° and 36°, serving the whole region of al-ʿIrāq, and on the Paris astrolabe of Aḥmad ibn Khalaf (#99—**XIIIc-2**) plates for 21° (Mecca), 24°, 29;55° (*Miṣr*, that is, Fustat), 31°, 34°, 36°, 37° (Harran), and 39°, on the Kuwait astrolabe of Nasṭūlus (#3501—**XIIIc-3.1**) a single plate for 33° and 36°, and on the Kuwait astrolabe of al-Khujandī (#111—**XIIIc-9**) plates for 21°, 24°, 27°, 30°, 33°, 36° 39° and 42°. See further **XVI**. And see also **3.17** for information on astrolabes that look like our Baghdad piece, but were actually made centuries later, this being reflected in the fact that they have plates for specific latitudes.

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47 Somewhere in an early text I have read words to the effect that it was al-Khwārizmī who was the first person to mark the azimuth curves on an astrolabe (*kāna awwal man sammata ʾl-asṭurlāb*), but I forgot where.

48 See King, "Geography of Astrolabes", especially pp. 6-9, now in **XVI-2-3**.

49 Kunitzsch, "10th-Century Andalusī Astrolabe".

50 See Maddison, "The Barber's Astrolabe".

51 King, "Geography of Astrolabes", now in **XVI**.

12 The latitudes of the plates

Since the length of daylight depends on the obliquity of the ecliptic, the latitudes of the climates, defined in terms of the lengths of maximum daylight, change slowly over time (see the table in **XVI-2**).[52] The latitudes given for the climates on the plates of the Baghdad astrolabe are correct (to the nearest degree) *only* for the Ptolemaic obliquity. Although better values were derived in the 9th and 10th centuries, Muslim instrument-makers remained faithful to Ptolemy's value until the 16th century.

13 The inscriptions on the plates

Even though F&N made a mess of copying the star-names, I would assume that they reproduced the inscriptions on the mater and plates correctly for the essential part is repeated seven times. Therefore I find it surprising that an Abbasid astrolabist would have written *iqlīm al-awwal* ... , *etc*., rather than the correct *al-iqlīm al-awwal* ... .[53] This would be more typical of an Iranian or Turkish engraver, but the inscriptions here are in *kūfī*.

14 Where was the astrolabe made?

One might think that this astrolabe might have been made in Baghdad, where, it appears, al-Fazārī and his contemporary Yaʿqūb ibn Ṭāriq were active in the late 8th century. (Baghdad was founded in 762.) But before we accept such a provenance, we should consider the fact that the astrolabe does not serve the latitude of Baghdad. That latitude is 33°20′, and already in Abbasid texts from the early 9th century, we find values of 33°, 33;9° and 33;25°.[54] In fact, though, Baghdad lies roughly on the boundary between the third and fourth climates. So the astrolabe could not, in fact, be used there. In some medieval Arabic treatises on the use of the astrolabe we read that if one is working in a locality that is not served by the plates of an astrolabe, one can interpolate appropriately between results using two plates successively, one for a higher latitude and the other for a lower latitude, but what is intended here is a degree or two of latitude difference, not half a climate (which would be about three degrees) on each side.

This presents us with a problem, for which one solution would be to suppose that the astrolabe was made in Ḥarrān. This city is at latitude 36°51′; Ptolemy had 36;10°, al-Khwārizmī 36;40° and 37;0°, the astrolabists Aḥmad ibn Khalaf and Nasṭūlus 37;0° and 35;0°, respectively, and al-Battānī, who actually hailed from Ḥarrān, had 36;40°.[55] In any case, Ḥarrān is indeed near the *middle* of the 4th climate.[56]

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[52] For a table by al-Bīrūnī, based on obliquity 23;35° and with several corrupt values, see al-Bīrūnī, *Astrology*, p. 138. See also Dallal, "Al-Bīrūnī on the Climates", pp. 12-18.

[53] Compare Kunitzsch, "10th-Century Andalusī Astrolabe", pp. 116-117, where the inscriptions are written properly.

[54] On early values for the latitude of Baghdad see Kennedy & Kennedy, *Islamic Geographical Coordinates*, pp. 55-56; King, "al-Khwārizmī", p. 2; *idem*, "Earliest Muslim Geodetic Measurements", pp. 226-227; and *idem*, "An Arabic Treatise on the *Quadrans Vetus*", pp. 238 and 250, now in **XIIa-A**, comm. to ch. 10.

[55] Kennedy & Kennedy, *Islamic Geographical Coordinates*, pp. 134-135. For the values of Aḥmad ibn Khalaf and Nasṭūlus see **XIIIb-2** and **3**.

[56] It may be that the early Abbasid value 33;9° was actually calculated for the boundary of the climates using

But there is another solution, which would allow us indeed to accept Baghdad as the provenance: the astrolabe was copied in the Greek tradition, and the purpose of the seven plates for the climates was to make the astrolabe *universal*. Therefore, *in theory*, it *does* work for Baghdad and, for that matter, anywhere else within the seven climates of the Ptolemaic world.

There is also a more advanced kind of astrolabe that was developed in Baghdad in the 9th century, with a rete on which the northern and southern parts of the ecliptic are made symmetrical to each other and then combined as a single circular arc. In **XIIId** I have investigated a very unusual Italian astrolabe (#169) from *ca*. 1300 with a diameter of a mere 5.9 cm that is the sole surviving medieval example of this tradition. This piece has a single set of astrolabic markings for latitude 24°, that is, the 2nd climate, and no other markings were included originally, because those for latitude 24° are on the mater and there is no room for any plates. I have argued that this tiny Italian astrolabe was copied from or at least inspired by an *Islamic* astrolabe of the same very unusual (and highly sophisticated) kind, which would have had a plate *for each of the seven climates*. I also suggested that the proto-type to this ingenious instrument was developed in *Baghdad*, for it is there that we encounter the earliest textual information on this astrolabe-type.

But there is another point worth mentioning: in two of the most important treatises on instrument construction from the Islamic Middle Ages, there are illustrations and even tables for the latitude of 36° and no other latitude. I refer to the treatise on astrolabe construction by al-Bīrūnī, apparently compiled in Gurganj in Central Asia *ca*. 1000[57] and the treatise on over 100 kinds of instruments by Najm al-Dīn al-Miṣrī, compiled in Cairo, *ca*. 1325.[58] Now the latitude of Gurganj is 42°18′, and the latitude of Cairo is 30°3′ and already Ibn Yūnus in the late 10th century measured it as 30;0°. So why on earth should al-Bīrūnī, working in Gurganj, and Najm al-Dīn, working in Cairo, both present "worked examples" for latitude 36°? The answer is surely related to the fact that the middle of the 4th climate, taken as 36°, corresponds to the "middle" of the inhabited earth,[59] but no less to the fact that worked examples in Ptolemy's *Planisphaerium* and *Almagest*, as well as the astrolabe treatises of Theon (*ca*. 325) and Sebokht (*ca*. 650), is also 36°, presumably originally intended for Rhodes, happily at the middle of the 4th climate.[60]

For these reasons, I am inclined to think that *this astrolabe may well have been made in Baghdad, even if it cannot be conveniently used there*.

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the Indian value for the obliquity. See King & Maier, "London Catalan Astrolabe", pp. 692-693, for a reconstruction of a medieval value of the latitude of Valencia by the same technique.

[57] In the published version of al-Bīrūnī's introduction to astronomy and astrology, also compiled in Gurganj, an astrolabe plate is illustrated for latitude 30°, rather than 36°: see al-Bīrūnī, *Astrology*, facing the page numbered 195b.

[58] Charette, *Mamluk Instrumentation*, pp. 28-31.

[59] Charette (*ibid*.) is more cautious: after pointing out that nothing precludes Najm al-Dīn from having visited Aleppo or to have been commissioned to compose his treatise for someone in that city, he writes "another possibility would be that he chose the latitude of 36° as a purely didactical example for the fourth climate, but I do not consider this to be very likely."

[60] Neugebauer, "Origin of the Astrolabe", pp. 242, 247-248, and 250.

15 The limited markings on the back

The only markings on the back are two altitude scales. This is also the case with the Brescia Byzantine astrolabe (on which the quadruple shadow-box is a later addition),[61] and the Kuwait astrolabe of Nasṭūlus (#3501—**XIIIc-3.1**). The Paris astrolabe of Aḥmad ibn Khalaf (#99—**XIIIc-2**) has a shadow-scale on the lower right rim. The markings in excess of these on the back of the Oxford astrolabe of Khafīf (#1026—**XIIIc-1.1**) are later additions by the Armenian who also made other changes to the instrument.[62] The development of different kinds of shadow-scales, universal horary quadrants, latitude-specific quadrants, trigonometric quadrants, and astrological tables, took place in the 9th century, as we know from texts, and as we find on some other 9th- and 10th-century instruments.[63]

16 The later modifications to the astrolabe

There are three possibilities we should mention, if only to dismiss the first two:

(1) Aḥmad ibn Kamāl made the rete himself to fit an old mater and three plates. This is not to be taken seriously, because we have several Ottoman examples of new up-to-date retes being added in Ottoman times for existing astrolabes.[64] Aḥmad ibn Kamāl would have needed to have copied this rete from an existing one that was in a state of collapse.

(2) Aḥmad ibn Kamāl came across a complete astrolabe whose rete bore no inscriptions. These he added in *naskhī* script. We can dismiss this outright because of the name *al-jabbār*.

(3) Aḥmad ibn Kamāl came across a complete astrolabe and removed the original *kūfī* inscriptions from the rete, replacing them with his own *naskhī* inscriptions. I deem this to be the most likely scenario, although when inscriptions are removed in this way there are usually traces,[65] and here there appear to be none.

We have already noted that Aḥmad ibn Kamāl marked three pointers with the "wrong" names, choosing names more appropriate for his time.

He also felt the need to insert a name on the blunt end of the circumferential frame opposite *qalb al-ʿaqrab*; Ottoman instruments featured *dhanab al-qayṭus* on a pointer based in this vicinity but with a star-position quite close to the equatorial bar.[66]

He re-engraved the names of the zodiacal signs on the ring for the ecliptic using the standard Arabic forms. Most early Islamic retes (for example, those of Khafīf, Aḥmad ibn Khalaf and Nasṭūlus) bear the name *al-samaka*, "the fish", for Pisces, rather that the indigenous Arabic term *al-ḥūt*, "the large fish",[67] which regained precedence and was, inevitably, used by the person who engraved the star-names in *naskhī* (perhaps, Aḥmad ibn Kamāl).

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[61] See n. 9 above.

[62] The back is illustrated in Mayer, *Islamic Astrolabists*, pl. I.

[63] On early developments to the standard astrolabe see now **XIIIa**.

[64] For just one example, an early-14th-century ʿIrāqī astrolabe (#3534) with an Ottoman Turkish replacement rete from *ca*. 1700 (#3533), see *Paris IMA Astrolabe Catalogue*, pp. 86-88 (no. 4).

[65] See the oldest preserved Western Islamic astrolabe, #110=#135—1.3.2, illustrated in Gunther, *Astrolabes*, II, pp. 244-245 (no. 110) and 280 (no. 135), and now **Fig. XIIIa-1.2**. The medieval Italian who started to remove the Arabic names of the zodiacal signs to replace them with ones in vernacular Latin soon gave up.

[66] As on the rete mentioned in n. 64.

[67] See Paul Kunitzsch in the EI_2 article "Minṭaḳat al-burūdj".

17 Could the astrolabe not date from a later period?
I know that various colleagues and friends, such as Paul Kunitzsch and Anthony Turner, will pose the question: "Could the astrolabe not be a much later production?". To answer this question and counter its implications I cite two instruments:

1) The Kuwait astrolabe of Nasṭūlus (#3501—**XIIIc-3.1**), dated 315 Hijra [= 927/8], which looks like a larger version of the Baghdad astrolabe. The scale of the limbus, the *kūfī* engraving, the rete, the engraving on the plates, all this is very similar to the Baghdad astrolabe. So what is different? There is a single plate for latitudes 33° (Baghdad) and 36° (4th climate), not a set for the seven climates, and there is nothing beyond a single altitude scale on the back. But I hasten to mention that the astrolabe was already long out-of-date when it was made. One only has to compare this piece with the astrolabe of al-Khujandī (#111—**XIIIc-9**), constructed roughly 50 years thereafter, to realize that Nasṭūlus was playing a very traditional game here.
2) The front of an astrolabe made by Muḥammad ibn Ḥāmid ibn Maḥmūd in Isfahan in the year 571 Hijra [= 1175/6] (#4199—**XIIIc-B1**), which is also virtually identical with the Baghdad astrolabe.[68] The scale of the limbus, the *kūfī* engraving, the rete, the engraving on the plates, all this is very similar to the Baghdad astrolabe. The diameter is only 8.9 cm. So what is different? The two-fold answer is quite simple: first, the plates are for the latitudes 30°, 32°, 34° and 36°, not for the seven climates, and second, the back has, in addition to a trigonometric quadrant, a solar quadrant with graphical representations of the solar altitude at the times of the midday and mid-afternoon prayers for the latitude 32°, that is, Isfahan.

There are several more examples one could cite, but with these considerations I hope to have convinced even the most sceptical of my colleagues.

4 Another early Abbasid astrolabe of the same kind

There is actually another such piece that I have seen in a private collection (#4020—1.2.14): it is badly corroded, so badly that the rete has fragmented and disappeared and all that remains of the alidade is a "shadow" across the back. But two features are without question: first, the diameter is about 8.5 cm, so it is the same size as our Baghdad astrolabe; and second, one can just see the ligature *lām-wāw* on the only visible plate (but no other markings). This stands, significantly, for latitude 36°. There is alas nothing more to say about this piece, except to bemoan its fate, and to predict that any attempt to separate the plates will reduce the whole lump to dust.

[68] See *Kuwait Catalogue*, pp. 89-91, also 92.

5 Concluding remarks

This tiny unimposing astrolabe from a neglected collection turns out to be an artefact of monumental cultural significance, serving as a kind of symbol of the way in which Muslims came to terms with Greek science. The simple design of this very basic astrolabe was not enough for Muslim astronomers, who, within a few decades, made substantial developments to the astrolabe and decorated it to make of it a scientific work of art.

The wretched photos of the Baghdad astrolabe that I have presented here, the same that were published by Faransīs and Naqshabandī, were sent to me by the Baghdad Museum in 1990. In that same year, curators from that museum were involved, not necessarily of their own volition, in the looting of the Museum of Islamic Art in Kuwait, sorting the original pieces for transport to Baghdad from the copies that were thrown on the floor of the museum, which was then burned to the ground. Fortunately, the astrolabes were on loan to an exhibition in the U.S. at the time. The astrolabes stolen by Iraqi troops from private collections in Kuwait have still not been recovered. Little did Saddam Hussein, who gave all the orders then, realize that the cultural heritage of Mesopotamia would suffer a like fate but on a far greater scale in 2003.

In any case, these happenings are enough to make various people from over a millennium who merit only our gratitude—the anonymous Abbasid craftsman who made this astrolabe; Aḥmad ibn Kamāl, who modified it; ʿAbd al-Ḥalīm al-Ḥāfātī, the astronomer who acquired it for his private collection, and his son Aḥsan al-Dīn, who donated it to the Museum; as well as Bashīr Faransīs, a Christian, and Nāṣir al-Naqshabandī, a Sunnī Muslim, the scholars who described it to the best of their ability—turn over in their graves.

APPENDIX: OTHER INSTRUMENTS BELONGING TO THE ARCHAEOLOGICAL MUSEUM, BAGHDAD

There follows a list of the astrolabes listed by F&N after the first, which is that of Aḥmad ibn Kamāl. The first two (2-3) are from Safavid Isfahan,[1] and the next two (4-5) are from Moghul Lahore (to which L. A. Mayer had a curious aversion, for he listed not a single one of the prolific astrolabists from that milieu). The fronts and backs of these four pieces are illustrated in **Figs. A1-2**. The provenance of the next (6) is Iran, and of the last (7) uncertain. The International Instrument Checklist numbers come from Price *et al*., *Astrolabe Checklist*, p. 85 (*sub* BAM). The reader should be aware that there are dozens of astrolabes that survive from Safavid Iran and from Moghul Lahore. They have never been studied as a group: a few detailed descriptions of individual instruments are available.[2] The instruments listed here (at least 2-5) would not be likely to contribute much to our knowledge of late Islamic instrumentation beyond a few art-historical considerations, although, under optimal circumstances (that is, if they did not belong to a museum and if they were not identified as stolen), each of them could fetch €10-20,000 on the market.

(2) An astrolabe by Muḥammad Khalīl ibn Ḥasan ʿAlī Iṣfahānī (name misread as Ḥasan ibn ʿAlī), supposedly dated 1020 Hijra [= 1611/12] although his other pieces are dated between 1093 and 1119 H [= 1682-1708] so the date must be off by a lunar century, plain throne, 5 plates, gazetteer, diameter 11.8 cm, Museum inventory no. 9722, International Instrument Checklist #3715, F&N, pp. 13-19; mentioned in Mayer, *Islamic Astrolabists*, supp., p. 295.

(3) Another astrolabe by Muḥammad Khalīl, also supposedly dated 1020 H [= 1611/12] (see 2 above), ornate throne, 5 plates, gazetteer, diam. 16.4 cm, inv. no. 9719, IIC #3716; F&N, pp. 19-25, mentioned in Mayer, *Islamic Astrolabists*, supp., p. 295.

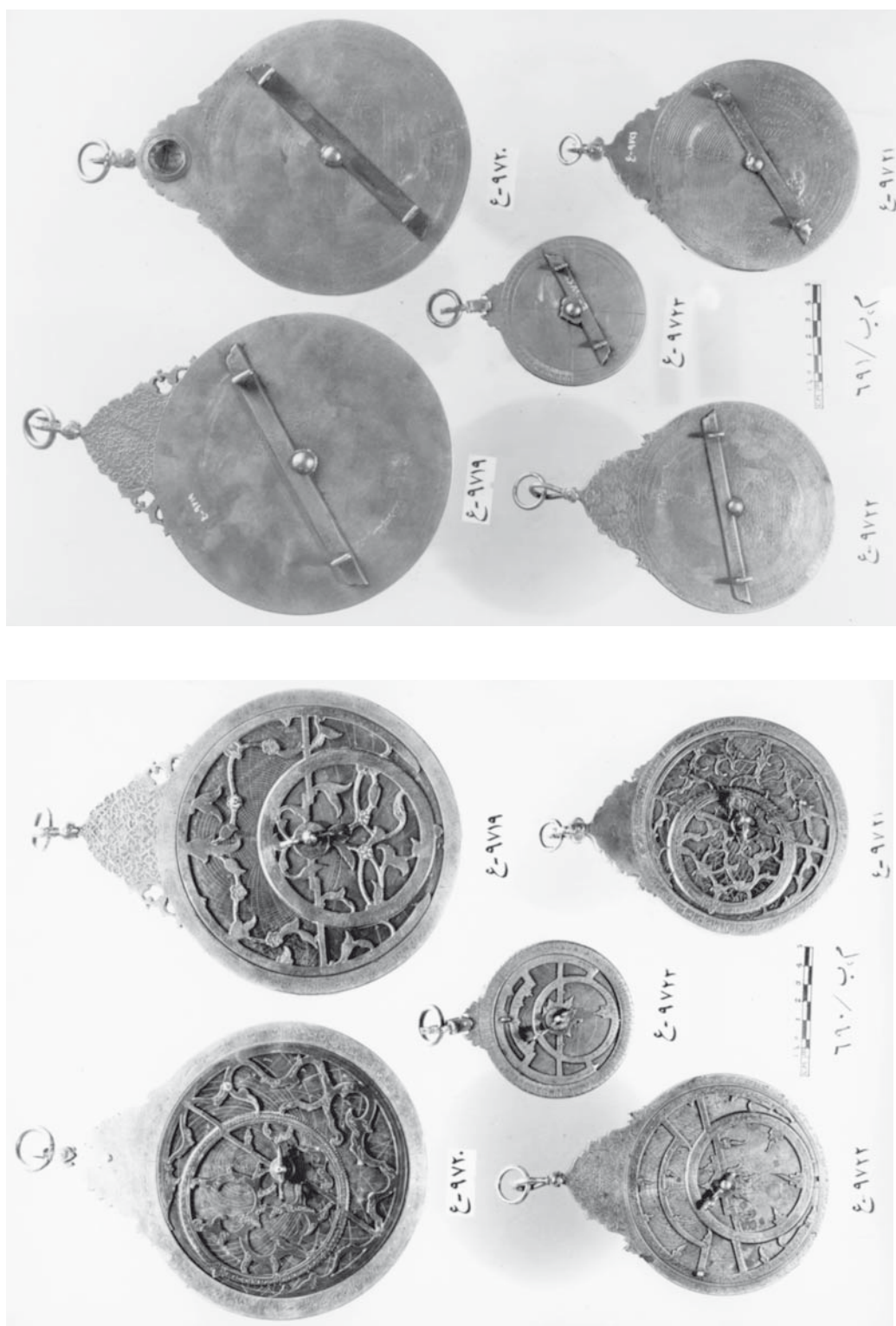
(4) An undated astrolabe by Qāʾim Muḥammad and Muḥammad Muqīm, sons of Mullā ʿĪsā ibn Allāh-dād of Lahore, plain throne, 5 plates, gazetteer, diam. 12 cm, inv. no. 9727, IIC #3821, F&N, pp. 25-28.

(5) An astrolabe by Qāʾim *B-h-r-y* (?) ibn ʿĪsā ibn Allāh-dād of Lahore, dated 1041 H [= 1631/32], plain throne, 7 plates, gazetteer, inv. no. 9720, diam. 12 cm, IIC #3820, F&N, pp. 28-32. The name of the maker is new to the literature, and probably results from a misreading.

(6) A mater and rete, unsigned, dated to the 10th/16th century, gazetteer on mater without Indian cities (hence Iranian), diam. 9.5 cm, inv. no. 3685, F&N, p. 32.

(7) A complete astrolabe, unsigned, undated, 2 plates for 30°/36° and 33°/34°, described as “badly made”, diam. 13.5 cm, inv. no. 741, F&N, p. 32.

[1] On these schools see most recently King, *Mecca-Centred World-Maps*, pp. 262-274, and Sarma, “Lahore Astrolabists”.

[2] The best are Morley, “Astrolabe of Shāh Ḥusayn” (1865), and Frank & Meyerhof, “Mogulisches Astrolab” (1925).

Figs. A1-2: The fronts and backs of five of the seven Baghdad astrolabes. The astrolabe of Aḥmad ibn Kamāl is in the middle. [Courtesy of the Archaeological Museum, Baghdad.]

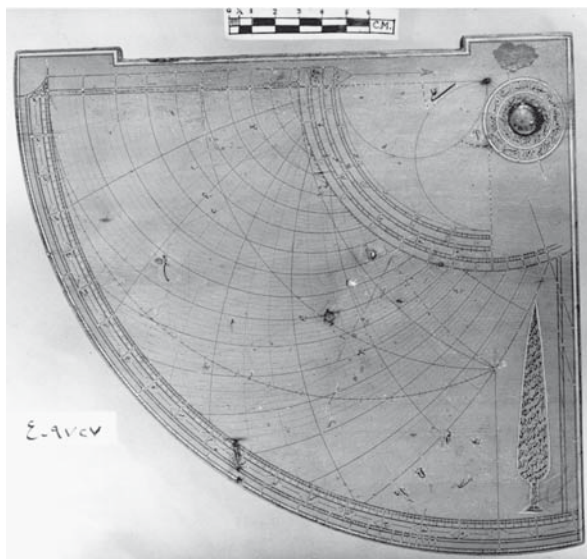



Fig. A3: The astrolabic markings on a quadrant made by ʿAlī for latitude 35°. [Photo originally from the Archaeological Museum, Baghdad.]

Fig. A4: The compass and inside of the cover of a qibla-box. [Photo originally from the Archaeological Museum, Baghdad.]

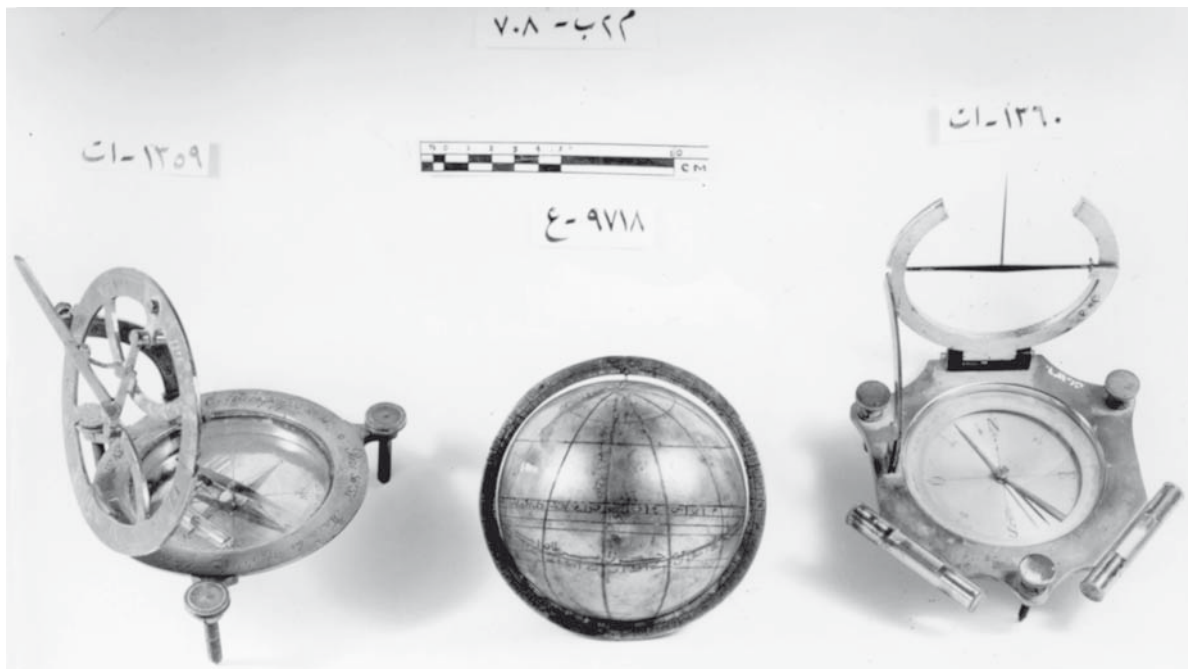



Fig. A5: Three more instruments from Baghdad. The European dial on the left bears inscriptions in Russian, and one can read the latitudes of Moscow (55°15'), St. Petersburg (59°56'), Riga (56°51'), and Poltava in the Ukraine (49°55'). The Islamic globe in the middle (inv. no. 9718) has no great merit. No inscriptions are visible on the other European dial on the right. [Photo originally from the Archaeological Museum, Baghdad.]

Three additional photos of Baghdad instruments were given to me in 2000 by Dr. Sonja Brentjes from the collection of her father, Professor Burehard Brentjes. One of these is a typical Ottoman astrolabic quadrant made of wood. The inv. no. is 9727, and the axial radii are 23.8 and 22.0 cm., and only a photo of the front is available to me: see **Fig. A3**. The maker identifies himself simply as ʿAlī, and the latitude underlying the astrolabic markings is 35°, probably intended for somewhere in N. Iraq. All of the usual markings for the prayers and festivals are present (see **XIVb-10**). Then there is a qibla compass typical of late Iranian devices of this kind: see **Fig. A4**. The inv. no. is 9717 and the radius is 8.2 cm. Slightly unusual are the instructions in Persianized Arabic enclosed in four concentric annular extended quatrefoil cartouches (see **XV-3.26**) on the inner base of the compass. The needle is still intact.

Fig. A5 shows three more Baghdad instruments.

Part XIIIc

The earliest astrolabes from Iraq and Iran (*ca*. 850 to *ca*. 1100)

Dedicated to the memory of
Louis-Amélie Sédillot, Vincenzo Mortillaro, Bernard Dorn,
Almerico da Schio, Eduardo Saavedra,
Lewis Evans and Robert T. Gunther,
Marcel Destombes, and Leo Ary Mayer

DEDICATION, ACKNOWLEDGEMENTS AND NOTES TO THIS VERSION

This study is dedicated to the memory of all those scholars of the 19th and early 20th century who by their enthusiasm for astronomical instruments and by their diligent studies paved the way for the present work. An account of their contributions is presented in **0b** below.

The following descriptions were taken from my unpublished catalogue of medieval Islamic and European instruments to *ca*. 1550 (see **XVIII**).

The first version of the descriptions of the Kuwait Nasṭūlus astrolabe (**3.1**) and the al-Khujandī astrolabe in a private Kuwaiti collection (**9**) was published as "Early Islamic Astronomical Instruments in Kuwaiti Collections", in *Kuwait: Art and Architecture—Collection of Essays*, Arlene Fullerton & Géza Fehérvári, eds., Kuwait (no publisher stated), 1995, pp. 76-96. In that I presented a series of instruments that were preserved either in the Dār al-Āthār al-Islāmiyya in Kuwait, which had recently been ransacked by Iraqi troops, or in the once splendid private collection of Shaykh Jasim al-Homeizi, who had fled Kuwait and lost all but one pieces—fortunately the astrolabe of al-Khujandī described here—from his collection. In the present version, I have relegated two of the Kuwaiti pieces to an appendix, rather than dump them because they are not from 10th-century al-ʿIrāq.

I have not finished with these astrolabes yet. I would like first to see how my descriptions are received and reviewed by colleagues, and then, perhaps, publish these again together with descriptions of *all* other Islamic pieces, Eastern and Western, up to, say, the end of the 13th or the 14th century.

Fig. 1: This little "Smiley" is part of the decoration on the magnificent astrolabe of the astronomer al-Khujandī made in Baghdad in the year 984/85 and described in **9** below. With tens of thousands of Iraqis killed in the course of the 2003 invasion and subsequent occupation, there has been little to smile about in Iraq of late. [Photo by the author, courtesy of the owner.]

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0a Introductory remarks

> "(The astrolabe) was perfected by Arabic and Persian scholars ... ." Harold N. Saunders, *All the Astrolabes* (1984), p. 2a.

> "Dire que l'astrolabe fut 'perfectionné par les érudits arabes et perses' est prétentieux dans le mesure ou nous ne savons pas sous quelle forme l'instrument leur fut transmis, alors que l'instrument décrit en syriaque par Severus Sebokht est juste aussi perfectionné que les plus anciens instruments musulmans survivant au 10^{e} siècle." Anthony J. Turner, "Review of Saunders, *All the Astrolabes*", (1990), p. 357.

The making of astrolabes was centred in Baghdad in the 9th century but during the 10th century spread to such centres as Rayy and Isfahan, as well as to al-Andalus. My purpose here is to present descriptions of all such instruments from Baghdad, Rayy and Isfahan up to the end of the 10th century. Since *not a single Eastern Islamic astrolabe survives from the 11th century* (!), I include one that was made in Isfahan in 1102/03, but refrain from discussing the next batch that includes instruments made in Baghdad and Isfahan in the 12th and 13th centuries. I have referred already to two Andalusī instruments from the 10th century (**X-4 and XIIIa-1**), but shall resist the temptation to present the dozen or so Andalusī astrolabes from the 11th century. In passing, we note that *not a single Western Islamic astrolabe is known from the 12th century*, that is, until the various pieces by the two prolific instrument-makers Abū Bakr ibn Yūsuf in Marrakesh and Muḥammad ibn Fattūḥ al-Khamāʾirī in Seville.

We can be grateful that a dozen or so Eastern Islamic astrolabes have survived from before *ca*. 1100. However, all of these are *standard* astrolabes. Far more interesting from a scientific point of view, and far more revealing of the brilliance of the scientific activity of this period would be the *non-standard* astrolabes that we know were also invented and actually made. These included astrolabes with mixed north-south projections, the remarkable "melon" astrolabe, the astrolabe fitted with an equatorium, plates for computing solar and lunar eclipses and predicting lunar crescent visibility. For a glimpse of what we are missing, we must in most cases turn to the texts, although occasionally we can trace these developments in derivative medieval European instruments (see, for a good example, **XIIId**).

The following descriptions show how much can be gained from close inspection of the instruments. I have not discussed technological aspects of the instruments, for this is beyond my competence. Yet we can learn from the surviving pieces about the form in which the astrolabe was transmitted to the Muslims in the 8th century and we can witness some of the additions, both technical and decorative, that were made already in the late 9th and 10th centuries. The study of instruments takes us into the realm of mathematical geography, often with surprising rewards. The dedications can be revealing if one can identify the recipient. The instruments can teach us a great deal about decorative art. The quatrefoil on various early Islamic astrolabes such as that of al-Khujandī, which later appear on early European astrolabes, is just one case in point. The forms of the star-pointers and various frames on the rete, the decoration of the thrones, the calligraphy of the inscriptions, all these are useful in establishing provenance and dating if doubtful. But, finally, the instruments constitute material for a new chapter in the history of Islamic science. Only in the past 25 years have the most remarkable Islamic instruments—the astrolabe of al-Khujandī, the astrolabic *zīj* of Hibatallāh, the universal

astrolabe of Ibn al-Sarrāj, the sundial of Ibn al-Shāṭir, and the Isfahan world-maps—been studied for the first time. They each represent the culmination of scientific activity that knew no rival anywhere in the world at the time, and whose history is still being written.

0b The historiography of the earliest Eastern Islamic astrolabes

Of course, what we would really like to know, but never can, is where these instruments were made, by whom they were used, and where they were until they resurfaced, mainly, but not entirely, in European collections. Nevertheless, it is not without interest to see how these early Islamic instruments became known to modern scholarship. Their discovery is best traced by searching through the articles from the 19th and early 20th centuries reprinted in the six volumes *Arabische Instrumente in orientalistischen Studien* (1990) by Fuat Sezgin and his staff in Frankfurt. The following account gives a somewhat distorted view of the European rediscovery of Islamic astronomical instruments in general,[1] since it is restricted to those Eastern Islamic astrolabes before *ca*. 1100. The reader should bear in mind that Western Islamic astrolabes were being rediscovered at the same time, some by other scholars than those mentioned below.

In 1844 the French orientalist Louis-Amélie Sédillot (*fils*) published a description of **2** (#99), the astrolabe by Aḥmad ibn Khalaf in the then Bibliothèque royale in Paris.[2] Somehow, the Italian scholar Almerico da Schio (see below), was misrepresented by Gunther (see below) as having stated that this piece was actually from the 12th or 13th century.[3]

In 1848 the Italian scholar Vincenzo Mortillaro published an article featuring **8.1** (#100), the solitary mater of Ḥāmid ibn ʿAlī. He recorded all of the inscriptions and fortunately presented lithographs of the front and back.[4] Since the piece has been stolen from the Museo Nazionale in Palermo, which had later been entrusted with it, Mortillaro's illustrations are of prime importance to us. It is a complicated piece that still defies proper interpretation. In 1880 da Schio, questioning the early date of the name in the dedication, pronounced that the Palermo piece was actually to be dated to the 12th or 13th century;[5] this was unfortunately accepted by Gunther (see below) on da Schio's "competent authority".[6]

In 1865 the German orientalist Bernard Dorn, based in St. Petersburg, published the most

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[1] I hope that nobody will consider doing this before the publication of Brieux & Maddison, *Répertoire*. Even then, there are more important tasks for the field. The lesson to be learned here is that one should proceed with utmost caution, and that pronouncements by self-styled experts with little or no experience with instruments should be taken with a grain of salt.

[2] Sédillot-*fils*, *Mémoire*, pp. 172-174. Alas no lithographs were included, for these would probably have been better than the photos that the Library could produce nowadays.

[3] da Schio, *Due astrolabi di Valdagno*, pp. 250-251, accepts Sédillot-*fils*' dating. Gunther, *Astrolabes*, I, p. 230 (no. 99), reported the "questionable" dating by da Schio and dismissed Sédillot's dating to *ca*. 905, designating the piece "type of A.D. 950". The questionable dating refers to da Schio's remarks on the Palermo mater described by Mortillaro (see the next three notes).

[4] Mortillaro, "Astrolabio arabo del nono secolo", superseded in 1936 by Caldo, "Astrolabi di Palermo", esp. pp. 6-9, and figs. 1 and 2.

[5] da Schio, *Due astrolabi di Valdagno*, p. 53. The author presented a remarkable list of Islamic instruments known to him (pp. 53-60).

[6] Gunther, *Astrolabes*, I, p. 230 (no. 100), immediately following his description of no. 99 (see n. 3 above).

extensive of a series of articles on Islamic instruments in Russian collections, this dealing with one globe, one astrolabe and one quadrant. As a (most fortunate) afterthought, he included a lithograph of **4** (#1179), the back of a mater and plate that were in the collection of the Arabist Dr. Johann Gottfried Wetzstein of Berlin, together with a description.[7] This piece never resurfaced.

In 1878 at the IVth International Congress of Orientalists in Florence, the Spanish orientalist Eduardo Saavedra stated that **6** (#101) in the Tribuna Galileo in that city was indeed made for the French Pope Sylvester II, probably in Cairo.[8] For Gunther (see below), it became "The Astrolabe of Pope Sylvester II", but already the Spanish Arabist Eduardo Saavedra and Lewis Evans (see below) recognized the problems of the Latin engraving on the back. In 1895 Saavedra published descriptions of some astrolabes preserved in Madrid, appending a more detailed description of **6**, which a colleague had had copied in Florence. Inevitably he had problems with the markings on the back.[9] In 1945 the Spanish instrument specialist Salvador García Franco published an expert description of the piece, using an electrotype preserved in the Museo Naval in Madrid.[10]

At the 1878 Oriental Exhibition in Florence, **11** (#122), then in possesssion of Principe E. Tomaso Corsini, was exhibited. Gunther (see below) knew of this "Moorish astrolabe" but had no details beyond the date and the size. The markings on the back attracted my attention some years ago,[11] but the piece has not been previously published beyond a brief notice in a 1954 catalogue.[12]

In 1911 the Oxford collector Lewis Evans, in an article describing some of the astrolabes he had recently acquired, noted the existence of **2** and **6**, dismissing **8.1** as later than it was dated, on account of the (absurd) pronouncement of da Schio.[13]

In Robert Gunther's *Early Science in Oxford*, II (1923), only three astrolabes are listed from before the 13th century: **2** (described by Sédillot-*fils* but now dated *ca*. 950), **8.1** (no details available to him), and **10** (recently acquired by Lewis Evans).[14] But Gunther's heart was in the right place: he introduced his list of 22 Islamic astrolabes known to him with an English translation of Heinrich Suter's 1892 German translation of the scientific part of Ibn al-Nadīm's *Fihrist* (see now **0c**), and he determined to do more.

Gunther's *Astrolabes of the World* (1932) featured some 150 Islamic astrolabes (that is, from #3 through to #154), a monumental tribute to his diligence and enthusiasm, and no less proof of his recognition of the importance of the Islamic tradition.[15] However, at first sight, it is not clear which are the earliest Islamic pieces, not least because he treated "Persian" astrolabes

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[7] Dorn, "Drei arabische Instrumente", pp. 115-118, with an illustration of the back. On Wetzstein see Fück, *Arabische Studien in Europa*, p. 191.
[8] Saavedra, "Astrolabe arabe".
[9] Saavedra, "Astrolabios en el MAN", pp. 412-414.
[10] García Franco, *Astrolabios en España*, pp. 131-160 (no. 3).
[11] King, *Mecca-Centred World-Maps*, pp. 104-105.
[12] *Florence MSS 1954 Catalogue*, pp. 61-62 (no. 1105).
[13] Evans, "Some European and Oriental Astrolabes", pp. 225-226.
[14] Gunther, *Early Science in Oxford*, II, pp. 189-191. There is an illustration of the front of A1, recently acquired by Lewis Evans and recognized as the earliest known dated Islamic astrolabe (374 H), opp. p. 188.
[15] See the tribute in Simcock, *Robert T. Gunther*.

before "Arabian" ones. To his credit, he was able to include at least a few of those described in the sequel. With the help of an Oxford Arabist, he prepared a respectable description of **10** (#3), recently aquired by Lewis Evans and thought at the time to be the oldest surviving Islamic astrolabe. He knew of **2** (#99) from the description by Sédillot-*fils* but mistaken misdated it on the authority of da Schio (see above) and was aware of the existence of **8.1** (#100) but not of the fact that it had been published by Mortillaro, citing the doubts of da Schio (see above) on its early dating. He also knew of the two Florence pieces **6** (#101) and **11** (#122), presenting photos of the former and appropriately raising questions about it. It is significant that he was unaware of the major publication by Bernard Dorn in 1864 on Islamic instruments in St. Petersburg, and thus he ignored **4** (#1179). He had seen **9** (#111), which was offered to him for purchase, but, being very poorly advise by the Oxford Arabist David S. Margoliouth, who proposed "Aḥmad ibn al-Khiḍr of Najd" for the maker and "778 H" for the date (the sketch shows 774 H). Gunther could not believe the early date claimed by the vendor and let the piece slip through his hands: a great loss for the Oxford Museum.

In 1956 the prolific Leon A. Mayer of Jerusalem was able to document most of these productions by their makers (alas he overlooked unsigned pieces, which are just as important).[16] So he mentioned Khafīf (**1.1**, not **1.2**), Aḥmad ibn Khalaf (**2**), Ḥāmid ibn ʿAlī (**3.1**, but not **3.2**), Muḥammad ibn Shaddād (**4**, misidentified as Maghribī), Aḥmad and Muḥammad bb. Ibrāhim (**10**) and Muḥammad ibn Abi ʻl-Qāsim (**11**). He also mentioned Gunther's "Ḥāmid ibn al-Khiḍr al-Najdī" (**9**), correctly questioning the misreading of the date as 774 H and proposing 374 H, and bemoaning the fact that the piece had disappeared. In his 1959 supplement[17] he added the Cairo mater of Ḥāmid ibn ʿAlī (**8.2**) and, much to his credit, Aḥmad ibn Kamāl, citing the 1957 publication of Faransīs and Naqshabandī but not giving any details or their dating to the 10th century, probably dismissing the maker by virtue of the late form of his name (see now **XIIIb**).

In 1957, Francis Maddison catalogued some of the recent acquisitions in the Oxford Museum.[18] These included the two pieces by Khafīf, the complete astrolabe **1.1** (#1026), which he mislabelled "Syro-Egyptian", and the solitary rete **1.2** (#2529), "Syro-Egyptian?". Maddison, ever cautious with unsigned pieces, did not suggest they might be by the same maker. For comparison with both he cited **2**, **6**, **8.1** and **10**, as well as **8.2** (#3713), the Cairo mater signed by Ḥāmid ibn ʿAlī, of which this was the first mention as such (its later dated Mamluk inscription was already known in the literature).

In 1962, the leading French scholar of historical instruments, Marcel Destombes, was confronted with the task of finding a context for an astrolabe that had just come into his possession, and which he (rightly) believed was from 10th-century Catalonia. (He was also confronted by a group of academics in Paris who liked neither him, for he was not a member

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[16] Mayer, *Islamic Astrolabists.* It is interesting to compare this mine of information with a purely bibliographical survey of writings on Islamic astrolabes compiled by K. A. C. Creswell in Cairo in 1947 entitled "A Bibliography of Islamic Astrolabes".

[17] Mayer, "Supplement", esp. pp. 295 and 294.

[18] *Oxford Billmeir Supplement Catalogue*, pp. 16-18 (nos. 155-156). These designations were dropped in the *London SM 1976 Exhibition Catalogue* (see n. 26 below).

of their aristocracy, nor the astrolabe, which, not having looked at any other astrolabes, for academics work only on texts, they preferred to believe was a fake.) Now Destombes had the historical insight and good taste to compare his astrolabe with the earliest available Islamic astrolabes. Indeed, in his account of his new astrolabe and its significance, after presenting "l'astrolabe grec de Brescia", he devoted four pages to "les astrolabes arabes orientaux des IXe et Xe siècles" and then continued with "les astrolabes hispano-arabes au XIe siècle".[19] Beginning with Ibn al-Nadīm, he discussed **2** (#99), correcting the misreadings of Sédillot-*fils*, and the early instruments mentioned by Gunther and Maddison, namely, **1.1-2**, **6**, **8.1-2** and **10**. In particular, he was able to identify the former's misrendering "al-Najdī" as al-Khujandī, thus establishing for the first time the importance of **9** (#111). But perhaps the greatest achievement of Destombes in these few pages was to identify the relevance of the Baghdad astrolabe bearing the name "Aḥmad ibn Kamāl", which had been published in Baghdad in 1957 (see above and now **XIIIb**).

In the early 1970s Alain Brieux in Paris acquired **3.1** (#3501) and **9** (#111), had detailed descriptions prepared (which were privately circulated), and then sold them to two different Kuwaiti collectors. It was typical of the fervour in the circles of astrolabe *aficionado*s of the time that these same descriptions were not published immediately in appropriate journals. However, Maddison and Anthony Turner (see below) were under the (false) impression that their descriptions would be published in 1976.

Now the maker of the former signed himself "Xastūlus", where X can be read as a "B" or an "N". In 1974 Brieux and Maddison published a short note in which they argued for Basṭūlus, which "seems a perfectly good Arabic transcription of Απόστολος, consistent with Arabic transcriptions of other Greek proper names", rather than Nastūlus, which "would have no apparent explanation".[20] In a paper published in 1978, I attempted to show that our man was called Nasṭūlus not Basṭūlus, for the latter would be a singularly inappropriate epithet for a Muslim named, like the Prophet of Islam, Muḥammad ibn ʿAbdallāh.[21] Meanwhile, in the mid 70s, Alain Brieux had discovered **3.2** (#1131 = #4023), the undated Cairo mater of N/Bastūlus.[22] (As in the case of some other Western "discoveries", Brieux could not have known that the piece was known already and would be discussed in a 1977 master's dissertation at Cairo University.[23]) In 1983, Paul Kunitzsch and I published a second paper proposing the name

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[19] Destombes, "Astrolabe carolingien", pp. 12-16.

[20] Maddison & Brieux, "Basṭūlus/Nasṭūlus?". The argumentation in this well-documented article is carefully argued, but overlooks the inappropriateness of the name for any Muslim, let alone one called Muḥammad ibn ʿAbdallāh.

[21] King, "Nasṭūlus/Basṭūlus".

[22] I certainly remember Alain being very excited in Cairo when I met him there after he had been to the Museum of Islamic Art, but I forget the year. The Cairo mater is first mentioned in Muṣaylaḥī, *al-Asṭurlāb* (see next note), and again in King & Kunitzsch, "Nasṭūlus", p. 343, n. 1. It was already in Price *et al*., *Astrolabe Checklist*, under #1131, dated 714 H, the year of the Mamluk additions.

[23] See Muṣaylaḥī, *al-Asṭurlāb*, esp. pp. 56-57 on this piece, and pp. 54-56 on the Cairo mater of Ḥāmid ibn ʿAlī. Inevitably, as in the case of many Near Eastern publications, the author had little access to any relevant Western publications (actually, in this case, only W. Hartner's article in the *Survey of Persian Art*, and L. A. Mayer's, *Islamic Astrolabists*). He was a student of Islamic art and kindly gave me a copy of his thesis, which, under the circumstances, is a fine piece of work for a student.

Nasṭūlus as a variant (that was acceptable within the framework of Semitic philology) of the (attested) name *Nasṭūrus* over the (highly improbable) *Basṭūlus*.[24] However, as we shall see, the name Basṭūlus is now firmly established in the literature. In the sequel (**3**), I reproduce all that we known on this Nasṭūlus, mentioning some outstanding contributions by him to instrumentation that went far beyond the manufacture of standard astrolabes.

In 1972 Derek de Solla Price and his graduate students at Yale completed their astrolabe checklist (instruments now numbered, not consecutively, up to #3924), profitting from the expertise of Brieux and others.[25] They included **1.1**, **2**, **3.1**, **4** (no date), **6**, **8.1-2**, **9**, **10** and **11**.

For the 1976 exhibition "Science and Technology in Islam" at the Science Museum in London as part of the so-called "World of Islam Festival", the following pieces or graphics thereof were presented: **1.1**, **1.2**, **2**, **3.1**, **4**, **8.2**, **9**, **10**, **11**. Brief descriptions of each piece were prepared by Francis Maddison and Anthony Turner, but the catalogue was not ready for the exhibition and was alas never published.[26] The pathetic information on astrolabes in the coffee-table book on Islamic science that *was* published (*Islamic Science: An Illustrated Study*, 1976), includes a claim that "the earliest (astrolabe) extant is from 4th/10th century Isfahan", although six earlier astrolabes from al-ʿIrāq were on display in the Exhibition.[27]

In 1980, in the catalogue of the collection of Leonard Linton of Point Lookout, Long Island, the first description of **7** (#4022) appeared in print. The provenance was stated as "Syria" and the date as "10th century".[28]

In the introduction to his 1985 catalogue of the astrolabic instruments in the Time Museum, Anthony Turner listed **1.1-2**, **2**, **3.1-2**, **4**, **6**, **8.1-2**, **9** and **10**, himself adding a catalogue description of **5** (#4180), which he dated to the 10th or 11th century.[29]

In 1991, my colleague George Saliba published the first description of the Uffizi drawings of a third piece by Khafīf, **1.3** (#4030).[30] About the same time, various bits and pieces, **12.1-3**, were identified by the present writer. There was nothing else to do except prepare detailed descriptions of the entire corpus. In 1995 I published the two pieces in Kuwaiti collections, **3.1** and **9**.[31] Now I feel compelled to publish all the descriptions.

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[24] King & Kunitzsch, "Nasṭūlus".

[25] Price *et al*., *Astrolabe Checklist*, esp. p. 31, for the earliest dated Islamic astrolabes and those with early estimated dates.

[26] Listed as *London SM 1976 Exhibition Catalogue*. (The authors generously sent copies of their manuscript to interested colleagues.) The descriptions of the astrolabes on pp. 96-103 give no indication of the provenance. For **1.2** there is "no indication of the maker" (!).

[27] Nasr, *Islamic Science*, pp. 118-123, with several illustrations with incorrect captions (p. 243), and King, "Review of Nasr, *Islamic Science*", pp. 216-217 / 341b.

[28] *Linton Collection Catalogue*, p. 83, no. 160. The piece now belongs to the Science Museum, London, not a happy fate for an astrolabe (their scientific instruments are mainly stored in a warehouse near Olympia).

[29] *Rockford TM Catalogue*, pp. 13-15, esp. n. 28, and pp. 60-63 (no. 1).

[30] Saliba, "Astrolabe by Khafīf".

[31] King, "Kuwait Astrolabes".

0c Ibn al-Nadīm on the early history of the astrolabe in the Islamic world

I here present a new translation of the Arabic text of the *Fihrist* of the 10th-century Baghdad bibliographer Ibn al-Nadīm dealing first with the mid-8th-century astronomer al-Fazārī (A), and then with instrument-makers from 9th- and 10th-century Baghdad (B).[32] Names of makers from whose hands we have surviving instruments are printed bold.

الفزاري وهو أبو إسحق إبراهيم بن حبيب الفزاري من ولد سمرة بن جندب وهو أوّل من عمل في الإسلام أسطرلاباً وعمل مبطحًا ومسطحًا وله من الكتب كتاب القصيدة في علم النجوم كتاب المقياس للزوال كتاب الزيج على سني العرب كتاب العمل بالأسطرلاب وهو ذات الحلق كتاب العمل بالأسطرلاب المسطح

A) “al-Fazārī: he is Abū Isḥāq Ibrāhīm ibn Ḥabīb al-Fazārī ... and he is the first person in Islam to make an astrolabe and he made [it] plane (?? *mubaṭṭaḥ^an wa-musattaḥ^an*). He wrote the following books:

(1) A poem on astronomy (*al-Qaṣīda fī ʿilm al-nujūm*);
(2) a book on the gnomon for determining midday (*al-Miqyās li-’l-zawāl*);
(3) an astronomical handbook with tables arranged according to the Hijra calendar (*al-Zīj ʿalā sini ‘l-ʿArab*);
(4) a book on the use of the “astrolabe” which is the armillary sphere (*al-ʿamal bi-’l-asṭurlāb wa-huwa dhāt al-ḥalaq*); and
(5) a book on the use of the plane astrolabe (*al-ʿAmal bi-’l-asṭurlāb al-musattaḥ*).”

الكلام على الآلات وصنّاعها كانت الأسطرلابات في القديم مسطّحة وأوّل من عملها بطلميوس وقيل عملت قبله وهذا لا يدرك بالتحقيق وأول من سطّح الأسطرلاب أبيون البطريق وكانت الآلات تعمل بمدينة حران ومن ثم تشتّتت وظهرت ولكنّها زادت واتسع للصنّاع العمل في الدولة العباسية منذ أيام المأمون الى وقتنا هذا فإن المأمون لما أراد الرصد تقدم إلى ابن خلف المروروذي فعمل له ذات الحلق وهو بعينها عند بعض علماء بلدنا هذا وقد عمل المروروذي الأسطرلاب

أسماء الصنّاع ابن خلف المروروذي الفزاري وقد مرّ ذكره قبل هذا على بن عيسى غلام المروروذي خفيف غلام علي بن عيسى وكان حاذقا فاضلا أحمد بن خلف غلام علي بن عيسى محمد بن خلف غلام علي أيضا أحمد بن إسحق الحرّاني الربيع بن فراس الحراني سطولس غلام خفيف على بن أحمد المهندس غلام خفيف محمد بن شداد البلدي على بن صُرد حراني شجاع بن ... وكان مع سيف الدولة غلام سطولس ابن سلام غلام سطولس العجلى الأسطرلابي غلام سطولس العجلية ابنته مع سيف الدولة تلميذة سطولس

[32] On Ibn al-Nadīm see the EI_2 article by Johannes Fück. My translation is based on Ibn al-Nadīm, *al-Fihrist*, pp. 273 (A) and 284-285 (B) of Flügel’s edition. (This section of the translation of Bayard Dodge—II, pp. 670-672—is unreliable.)

B) "Discussion of the instruments (*ālāt*) and their makers (*ṣunnāʿ*). In ancient times astrolabes were plane. The first person to make (*ʿamala*) them was Ptolemy. It is said that they were made before his time, but this is not known with exactitude. The first person to make a plane astrolabe (*saṭṭaḥa ʿl-asṭurlāb*) was Abiyūn al-Baṭrīq. Instruments were made (*kānat tuʿmalu*) in the city of Ḥarrān. From there they spread (*tashattatat ? wa-ẓaharat*) [and] {text: *wa-lākinnahā*, lit. but} they increased (in number), and in the Abbasid realm, work became plentiful for the instrument-makers (*ṣunnāʿ*), from the days of al-Maʾmūn to this our own time.

When al-Maʾmūn wished to make astronomical observations, he selected [Khālid] {text: Ibn Khalaf} al-Marwarrūdhī, who made (for the Caliph) an armillary sphere, the same one which is still in the possession of one of the scholars of our city. al-Marwarrūdhī (also) made astrolabes.

The Names of the Makers are [Khālid] {text: Ibn Khalaf} al-Marwarrūdhī; al-Fazārī, who has already been mentioned; ʿAlī ibn ʿĪsā, the apprentice (*ghulām*) of al-Marwarrūdhī; **Khafīf**, the apprentice of ʿAlī ibn ʿĪsā, who was clever and superior; **Aḥmad ibn Khalaf**, apprentice of ʿAlī ibn ʿĪsā; Muḥammad ibn Khalaf, also an apprentice of ʿAlī; Aḥmad ibn Isḥāq al-Ḥarrānī; al-Rabīʿ ibn al-Farrās al-Ḥarrānī; [**Nasṭūlus**] {Flügel confused}, apprentice of Khafīf; ʿAlī ibn Aḥmad the engineer/geometer (*al-muhandis*), apprentice of Khafīf; **Muḥammad ibn Shaddād al-Baladī**; ʿAlī ibn Ṣurad [al-]Ḥarrānī; Shujāʿ ibn ... (?), an apprentice of [Nasṭūlus], who was with Sayf al-Dawla; Ibn Salm, an apprentice of [Nasṭūlus]; al-ʿIjlī al-Asṭurlābī, an apprentice of [Nasṭūlus]; al-ʿIjliyya, his daughter, who was with Sayf al-Dawla, (and who was) a pupil (*tilmīdha*) of [Nasṭūlus].

Some of the apprentices of Aḥmad and Muḥammad, the two sons of Khalaf, were Jābir ibn Sinān al-Ḥarrānī; Jābir ibn Qurra al-Ḥarrānī; Sinān ibn Jābir al-Ḥarrānī; Farrās ibn al-Ḥasan al-Ḥarrānī; **Abu ʿl-Rabīʿ Ḥāmid ibn ʿAlī** {[al-Wāsiṭī]}, an apprentice of ʿAlī ibn Aḥmad *al-muhandis*. Some of the apprentices of Ḥāmid ibn ʿAlī were Ibn Najiyya, whose name was ... (?) ... (?); al-Būqī, whose name was al-Ḥusayn, but he changed it to ʿAbd al-Ṣamad.

(Other) early instrument-makers were ʿAlī ibn Yaʿqūb al-Raṣṣāṣ and ʿAlī ibn Saʿīd al-Uqlīdisī, (as well as) Aḥmad ibn ʿAlī ibn ʿĪsā, near(er) to our own time."

Notes on chronology

Khālid al-Marwarrūdhī is known to have participated in the astronomical activities of the Caliph al-Maʾmūn *ca*. 825.[33] ʿAlī ibn ʿĪsā was his apprentice—let us put his activity at *ca*. 850. He had as apprentices both Aḥmad ibn Khalaf and Khafīf—let us put them at *ca*. 875. Now Nasṭūlus, the apprentice of Khafīf, made an astrolabe (**3.1**) in 927/28, so maybe we should put Khafīf *ca*. 900.[34] If it is to Aḥmad of the Banu ʿl-Munajjim family that Khafīf's Oxford astrolabe (**1.1**) is dedicated, then the two possible candidates were alive *ca*. 900.[35] Furthermore, Aḥmad ibn Khalaf made an astrolabe (**2**) for Jaʿfar (906-987), the son of the Caliph al-Muktafī

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[33] On Khālid see Sezgin, *GAS*, VI, p. 139; Sayılı, *The Observatory in Islam*, p. 464 (index); and King, "Earliest Muslim Geodetic Measurements", *passim*.

[34] George Saliba ("Astrolabe of Khafīf", pp. 110-111), also using Ibn al-Nadīm, puts Khafīf *ca*. 850.

[35] See n. 61 below.

bi-'llāh (d. 908, *reg*. 902-908), which would necessarily have been made in Jaʿfar's early years—let us say *ca*. 925. Apprentices of Nasṭulus were "with" Sayf al-Dawla (916-967), a man of keen scholarly interests, who was *amīr* of N. Syria from 945 until his death:[36] this surely means he attracted them to his court, let us say, *ca*. 950, after he had established himself in Aleppo and Mayyafariqin, and before he was overcome by sickness and Byzantines. Furthermore, ʿAlī ibn Aḥmad the engineer/geometer (*al-muhandis*) was apprentice of Khafīf, whom we have set *ca*. 875 or *ca*. 900 at the latest, so let us put ʿAlī *ca*. 925. Now he had as apprentice Abu 'l-Rabīʿ Ḥāmid ibn ʿAlī al-Wāsiṭī, who made an astrolabe (**8.1**) in 954, so our tentative chronological progression is confirmed.

0d Ibn Yūnus and al-Bīrūnī on the skills of the earliest astrolabists

The famous late-10th-century Egyptian astronomer Ibn Yūnus (**II-4.1.1**, *etc*.) writes as follows in the introduction to his *Ḥākimī Zīj*:[37]

إن أفاضل العلماء وحذّاق الصناع إنما يكون منهم في الزمان الواحد واحد في أكثر الأمر وربما وجد الواحد في زمان وعسر
وجود مثله إلا في زمان طويل كبطلميوس في علم البرهان وجالينوس في علم الطب وخفيف غلام علي بن عيسى في عمل
الاسطرلاب وحامد بن علي الواسطي

" ... of the most distinguished scholars and highly skilled craftsmen, there may only be one at any given time, and maybe there will be one, but it will be difficult to find another like him for a long time (thereafter), such as Ptolemy in the science of logical reasoning in astronomy and Galen in the science of medicine, and Khafīf, the *ghulām* of ʿAlī ibn ʿĪsā, and Ḥāmid ibn ʿAlī al-Wāsiṭī in the construction of astrolabes. ... "

Khafīf and Ḥāmid ibn ʿAlī al-Wāsiṭī are in the best of company here, and fortunately some instruments of both have survived: see **1.1-3** and **8.1-2**. Elsewhere, Ibn Yūnus mentions that he actually used an astrolabe made by Ḥāmid ibn ʿAlī and it is obvious that he had at least seen one by Khafīf.

The celebrated early-11th-century al-Bīrūnī (**II-2.2**, *etc*.), the leading scientist of the Islamic world, wrote that al-Khujandī, whom he had met in person, was unique in his abilities as a maker of astrolabes and other instruments.[38]

فأمّا هذا السدس الفخريّ فقد فاق ما عُمل قبله وبعده عظماً وصحة إذ كان أبو محمود أوحد زمانه في صنعة الاصطرلابات
وسائر الآلات وكانت نتيجته في مقدار الميل أولى بأن يعمل عليها ويقاس إليها ازدياد الميل الأعظم ونقصانه إذ كان يضبط به
الثواني فكيف الدقائق

[36] See the EI_2 article "Sayf al-Dawla" by Thierry Bianquis.
[37] Caussin, "Table Hakémite", pp. 38-39/54-55. I have corrected the obvious errors.
[38] al-Bīrūnī, *Taḥdīd*, text, p. 107, and transl., p. 75. The translation here is my own.

“The *Fakhrī* sextant (erected by Abū Maḥmūd Ḥāmid ibn al-Khiḍr al-Khujandī at Rayy) surpassed in both size and accuracy (the instruments of this kind) that had been constructed before and (what has been constructed) after, because Abū Maḥmūd was unique in his time in the construction of astrolabes and all (observational) instruments. His result for the obliquity of the ecliptic merited to be (generally) adopted (by other astronomers), and to be used (as a basis) to measure the increase and decrease of the obliquity, for he even fixed it with (the sextant) accurately to seconds, let alone minutes!”

This remark about his abilities, no mean compliment, coming, as it does, from al-Bīrūnī, is borne out by al-Khujandī’s sole surviving astrolabe: see **9**.

0e The earliest Eastern Arabic treatises on the construction and use of the standard astrolabe

Ibn al-Nadīm (**0a**) informs us that al-Fazārī (Baghdad, *ca*. 750) authored a treatise on the use of the planispheric astrolabe, alas lost.[39] Apparently, the earlier treatise of Apion al-Baṭrīq (Egypt (?) *ca*. 625) was also available in Arabic, but that is lost too.[40] Fortunately, we have two treatises on the construction and the use of the astrolabe by al-Khwārizmī (Baghdad, *ca*. 825).[41] The former has never been published,[42] the latter was translated into German by Joseph Frank in 1922.[43] An edition of the Arabic text of both treatises from the unique Berlin manuscript, with an English translation and commentary by François Charette and Petra Schmidl, is to be published soon, together with the earliest Abbasid writings on the trigonometric and horary quadrant.[44] I have recently published the text of the earliest treatise on the universal horary quadrant with movable cursor (the so-called *quadrans vetus*).[45] A treatise on the use of the astrolabe by ʿAlī ibn ʿĪsā was published by Louis Cheikho in 1913 and a German translation by Carl Schoy in 1927.[46] However, from internal evidence, it is not clear that the author is to be identified as the 9th-century Baghdad astrolabist with this name mentioned by Ibn al-Nadīm.[47] Richard Lorch has prepared an edition, as yet unpublished, of the remarkable treatise on astrolabe construction by al-Farghānī (Baghdad, *ca*. 850) with its many tables of coordinates for engraving altitude and azimuth circles on astrolabic plates.[48]

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[39] On al-Fazārī see the *DSB* article by David Pingree, and on his astrolabe treatise, Sezgin, *GAS*, VI, p. 124.
[40] See **XIIIe-4, 7** and **8**, and also Sezgin, *GAS*, VI, p. 103.
[41] On al-Khwārizmī see the *DSB* article by Gerald Toomer. Both of these treatises are extant in MS Berlin Ahlwardt 5973, copied *ca*. 1500.
[42] For the first account see King, “al-Khwārizmī”, pp. 23-27.
[43] Frank, “al-Khwārizmī über das Astrolab”, also Sezgin, *GAS*, p. 143 (confused).
[44] Charette & Schmidl, “al-Khwārizmī on Instruments”.
[45] See King, “*Quadrans vetus*”, and now **XIIa**.
[46] Cheikho, “*Kitāb al-ʿAmal bi-ʾl-asṭurlāb li-ʿAlī ibn ʿĪsā*”, and Schoy, “ʿAlī ibn ʿĪsā über das Astrolab”. See also Sezgin, *GAS*, VI, p. 144.
[47] The text bears not a trace of 9th-century influence. In some copies the author seems to be called al-Ishbīlī, “from Seville”, but the treatise contains not a trace of Andalusī influence.
[48] On al-Farghānī see the *DSB* article by A. I. Sabra, where this treatise is not mentioned; Sezgin, *GAS*, VI, pp. 150-151; and King & Samsó, “Islamic Astronomical Handbooks and Tables”, pp. 91-92.

Early treatises (from before *ca*. 1000) that are known only by citations and not by any surviving copies are those of: Māshāʾallāh, the Banū Mūsā, the Banu ʻl-Ṣabbāḥ, al-Kindī, the grandson ʿUmar of Khālid al-Marwarrūdhī, ʿUṭārid al-Ḥāsib, Thābit ibn Qurra, Ḥabash al-Ḥāsib and his son Abū Jaʿfar, *etc*.[49] One of the few that are available, but still unpublished, is that of Kūshyār.[50] We should also mention: a short treatise by Ibrāhīm ibn Sinān, of which the text has been published;[51] a study by Jan Hogendijk of the writings of Abū Naṣr ibn ʿIrāq and al-Ṣāghānī on the theory of seasonal hour curves on astrolabes (and sundials);[52] the treatise by Abū Sahl al-Qūhī on Astrolabe Construction", edited with translation and commentary by Len Berggren;[53] and two treatises by Abū Naṣr ibn ʿIrāq, translated by Julio Samsó.[54]

A highly significant treatise on non-standard astrolabes was compiled by al-Sijzī (Rayy, *ca*. 980) and an edition has been prepared, but not yet published, by Richard Lorch.[55] al-Sijzī mentions the inventors of different kinds of unusual astrolabes and cites examples of individual instruments and their dedicatees. The most important early treatise on astrolabe construction, partly based on al-Sijzī and cognisant of the contributions of such earlier scholar-craftsmen as Nasṭūlus, is the *Istīʿāb al-wujūh fī ṣināʿat al-asṭurlāb* by al-Bīrūnī (Ghazna, *ca*. 1025).[56] An edition (of sorts) of this has recently been published in Tehran.[57] The exhaustive treatises on the use of the astrolabe in 402 and 1760 chapters by ʿAbd al-Raḥmān al-Ṣūfī (Shiraz, *ca*. 1000) are available only in facsimile editions.[58]

Later Arabic and Persian treatises on construction and use of the standard astrolabe are legion and need not concern us here.[59] For just one later example, see the treatise on astrolabe construction by the Yemeni Sultan al-Ashraf *ca*. 1290 (**XIVa**).

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[49] Sezgin, *GAS*, VI, p. 128 (the Latin treatises associated with Messahalla are unrelated to this—see **XIIIe-1**), 147, 148, 154, 159, 161, 169, 175, 18, *etc*.

[50] Sezgin, *GAS*, VI, pp. 248-249.

[51] Uncritical Hyderabad 1947 edition: see Sezgin, *GAS*, VI, p. 194.

[52] Hogendijk, "Seasonal Hour Lines on Astrolabes and Sundials".

[53] Berggren, "al-Kūhī on Astrolabe Construction"; also Sezgin, *GAS*, VI, p. 219.

[54] Samsó, *Abū Naṣr*, pp. 75-88 and 89-104 (also Sezgin, *GAS*, VI, p. 244).

[55] Sezgin, *GAS*, VI, pp. 225-226, and my "Review", p. 58.

[56] On al-Bīrūnī see the *DSB* article by E. S. Kennedy, and on this treatise see Sezgin, *GAS*, VI, pp. 268-269. His other astrolabe treatises (*ibid*., p. 269) await investigation.

[57] The Tehran "edition" is listed under al-Bīrūnī, *Astrolabe Construction*.

[58] On al-Ṣūfī see the *DSB* article by Paul Kunitzsch. On his astrolabe treatise see Sezgin, *GAS*, VI, p. 215, and the facsimiles published in Frankfurt in 1986.

[59] This is not to say that some of them do not contain surprises for a diligent researcher. A first attempt to survey them, as yet not superseded, is Awwad, "Astrolabe Texts" (1957) (in Arabic). Dozens of titles could be added from the standard bio-bibliographical sources on Islamic science.

1 Three instruments by Khafīf, apprentice of ʿAlī ibn ʿĪsā

As we have seen, Ibn Yūnus mentions the skills of the astrolabists Khafīf and Ḥāmid ibn ʿAlī al-Wāsiṭī (**8**) alongside those of Ptolemy and Galen. Ibn al-Nadīm informs us that Khafīf was the apprentice (*ghulām*) of (the enigmatic) ʿAlī ibn ʿĪsā. In addition to an astrolabe bearing the signature of Khafīf (**1.1**) we also have a rete that can be safely ascribed to him (**1.2**). Only in 1991, some 16th-century Italian drawings of a third astrolabe by Khafīf (**1.3**) were published.

1.1 An undated astrolabe

International Instrument Checklist #1026.
Oxford, Museum of the History of Science: 57-84/155. Formerly in the Collection of J. A. Billmeir. Earlier provenance?
Brass. Diameter: 112 mm.
Bibliography: [Francis Maddison] in *Oxford MHS Billmeir Supplement Catalogue*, pp. 16-18 and pl. XXIIIa (front only); Mayer, *Islamic Astrolabists*, p. 54, and pl. I (back only); *London SM 1976 Exhibition Catalogue* (unpublished), p. 98; Tumanyan, *History of Armenian Astronomy*, pp. 174-177 (in Armenian), with a brief summary on p. 394 (in English); and Stautz, *Mathematisch-astronomische Darstellungen auf mittelalterlichen Instrumenten*, pp. 45-47 and 182.

The throne, cast in one piece with the mater, has a rectangular socle as base, with three lobes and one large hole on each side. The suspensory apparatus is a rather large shackle with a pear-shaped base and saddle holding a circular ring. The back of the throne bears an inscription in a rounded *naskhī* script. It reads:

خفيف غلام علي بن عيسى

“Khafīf, the apprentice of ʿAlī ibn ʿĪsā,”
there being no associated verb (compare **1.3**). On the front of the throne in the same script in the inscription:

برسم أحمد المنجّم السنجاري

“by order of (*bi-rasm*) Aḥmad al-Munajjim al-Sinjārī.”
This individual is not otherwise known to the modern literature. Although he was clearly an astronomer (*munajjim*), he is apparently not mentioned amongst contemporaneous Abbasid astronomers in the known sources.[60] Another possibility would be that he was a member of the Banu ʻl-Munajjim family.[61] I first thought that the inscription could not be original—not

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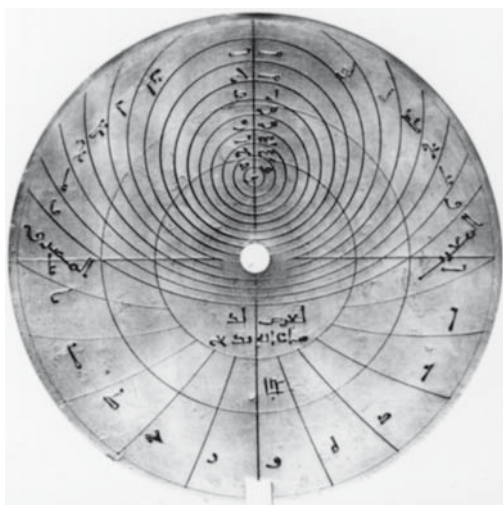
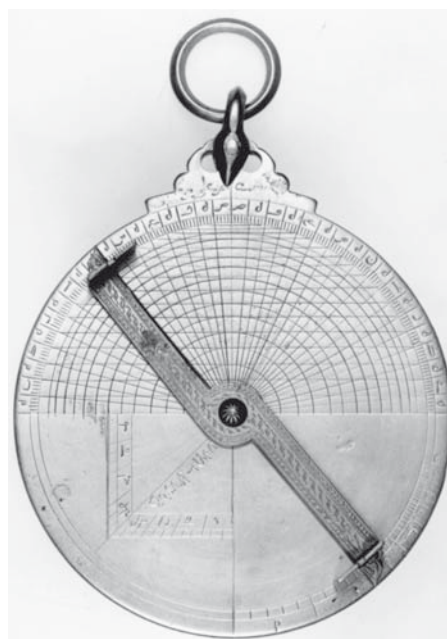
[60] Aḥmad ibn Muḥammad al-Ḥāsib al-Nihāwandī, also known as Aḥmad ibn Muḥammad al-Munajjim (Sezgin, *GAS*, VI, pp. 135-136), was active a few decades too early, and besides Nihāwand is not Sinjār.
[61] Since no astronomer with this name is known to us, it may be we are dealing with a descendant of Abū Manṣūr, a Zoroastrian appointed by the Caliph al-Manṣūr as astronomer/astrologer. We have an Abū ʿĪsā *Aḥmad* of unknown date but his brother Abū Aḥmad Yaḥyā lived 855-912, and an Abu ʻl-Ḥasan *Aḥmad*, son of Yaḥyā, who lived 875-939. Both the brothers *Aḥmad* and Yaḥyā and the latter’s son *Aḥmad* were scholars, but none appears to have been known as al-Sinjārī, that is, from Sinjār, west of Mosul. See further the EI_2 article “Munadjdjim, Banu ʻl-” by M. Fleischhammer.

a

b

c

Figs. 1.1a-c: The front and back of the only surviving complete astrolabe of Khafīf (#1026) and the plate for latitude 34°. [Courtesy of the Museum of the History of Science, Oxford.]

least because of the *naskhī* script and the fact that the expression “made / constructed by” is missing—but there is no need to doubt the accuracy of the attribution to Khafīf, especially now that **1.3** has come to light.

The scale on the rim is divided 5°/1°-5° (without tens and hundreds). The mater bears a peg at the bottom of the inside to hold the plates in position; otherwise it is devoid of markings.

The rete has a rectilinear equinoctial bar, of which the segments inside the ecliptic are about twice as wide as those outside. The lower equatorial bar lies just ouside the equator, and its supports are unduly wide; there is a handle on the left-hand support. There is a / \ -shaped frame below the central disc. The scale of the ecliptic is divided for each 6°, and the divisions are not labelled. The names of the zodiacal signs are standard, except that *al-samaka* is used for Pisces (compare **XIIIa-2.4** and **3.16**). The rete is similar to that of on the Kuwait astrolabe of Nasṭūlus (**3.1**), but somewhat less elegant. The star-pointers are dagger-shaped markings and serve 17 stars:

(**1**: complete astrolabe, **2**: single rete, **3**: drawing—see below)

raʾs al-ghūl	*al-rāmiḥ*
al-dabarān	*al-fakka*
al-ʿayyūq	*qalb al-ʿaqrab*
rijl al-jawzāʾ	*raʾs al-ḥawwāʾ*
mankib al-jawzāʾ	———————
al-yamāniya	*al-wāqiʿ*
———————	*al-ṭāʾir*
al-shaʾāmiya	*dhanab al-dajāja* (**1** and **3**) / *al-dajāja* (**2**)
qalb al-asad	*mankib al-faras* (**1** and **2**) / *mankib* (**3**)
———————	*kaff al-khaḍīb*

Burkhard Stautz has shown that the star-positions correspond very closely to the coordinates of al-Farghānī adjusted with the *Mumtaḥan* precession to *ca*. 925.

There are two original plates bearing altitude circles for each 6° and no azimuth circles. The associated lengths of maximum daylight cannot be linked to specific values of the obliquity. The latitudes served are:

33°	14;13^h	[0/+1]
34	14;18	[-1/+1]
35	14;22	[-2/0]
36	14;30	[0/+2]

The errors in the lengths of longest daylight are given for obliquity 23;51° and 23;33/35°. A third plate with identical features but different *kūfī* script is not original—see below. That this plate was fitted into our astrolabe by an innocent is evident from the fact that on it the cut-out is at the top of the plate rather than at the bottom.

The only original markings on the back appear to be the horizontal and vertical diameters, two altitude scales divided 5°/1° on the rims of the upper quadrants, and a shadow-scale to base 12 divided 5/1-5 up to 50 on the rim of the lower right quadrant. The trigonometric grid

that now graces the two upper quadrants is not carefully drawn and if it were original would have surely disqualified Khafīf from membership in the highest ranks of early Abbasid *asṭurlābī*s—see below.

Later markings
The trigonometric grid is most probably the handiwork of the Armenian who most certainly added the shadow square (to base 12 with scales divided 3/1 and labelled for each 3 digits) in the lower left quadrant with inscriptions in his own language, as well as the ornate and very Armenian decoration on the alidade and radial rule—see further **1.2**.

Replacemement parts
A single replacement plate with *kūfī* inscriptions bears altitude circles for each 6° for latitudes:

36°	14;28^h	[-2/0]
41	15; 0	[-1/+2]

The underlying obliquity is difficult to pinpoint, the errors shown being for obliquity 23;51° and 23;33°/23;35°, respectively. See also **12.3**.

1.2 A solitary rete

International Instrument Checklist #2529.
Oxford, Museum of the History of Science: 57-84/156. Formerly in the Collection of J. A. Billmeir. Earlier provenance?
Brass. Diameter: 143 mm.
Bibliography: [Francis Maddison] in *Oxford MHS Billmeir Supplement Catalogue,* p. 18 (no. 156); *London SM 1976 Exhibition Catalogue*, p. 99; Tumanyan, *History of Armenian Astronomy*, pp. 174-177 (in Armenian), with a brief summary on p. 394 (in English); and Stautz, *Mathematisch-astronomische Darstellungen auf mittelalterlichen Instrumenten*, pp. 45-47 and 183.

This rete (**Fig. 1.2**) bears *kūfī* inscriptions in the same hand as **1.1** above and also has *al-samaka* for Pisces on the ecliptic. There are dagger-shaped markers for 17 stars, and all of the original inscriptions have been duplicated in Armenian. The stars are listed under **1.1** above. Since the stars represented are precisely those on the astrolabe of Khafīf just described, and various other features (including the script, the lack of a star-pointer opposite *qalb al-ʿaqrab*, and the position of the handle on the left support of the lower circular bar), I see no problem in attributing this rete to Khafīf too. The star-positions are virtually identical to those on **1.1**. There is a small hole by the name of the star *al-fakka* whose purpose is not clear to me.

Later markings
The star names have been duplicated in Armenian—see further **1.1**.

1.3 Parts of an astrolabe illustrated in a 16th-century Italian drawing

International Instrument Checklist #4030.
Florence, Galleria degli Uffizi, Gabinetto dei Disegni e Stampi: U1454A recto and verso. Provenance?

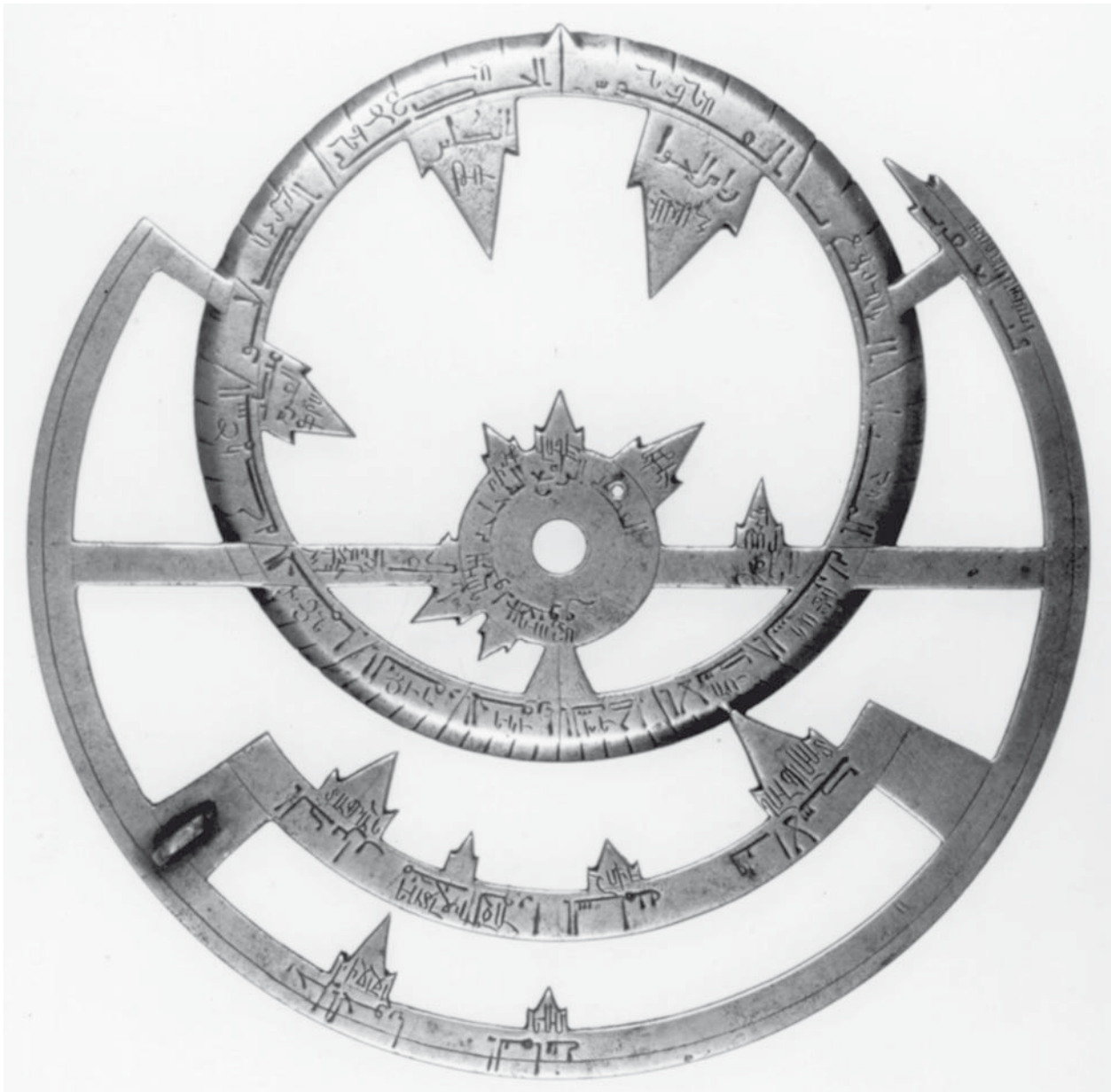
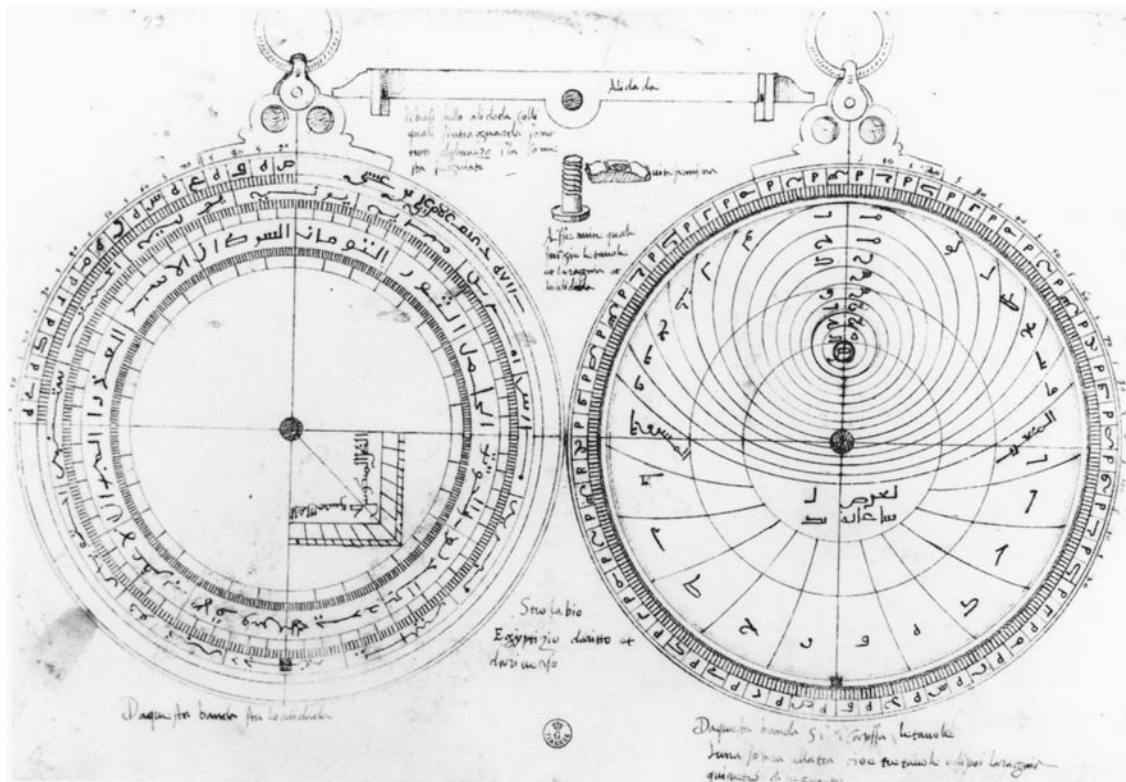
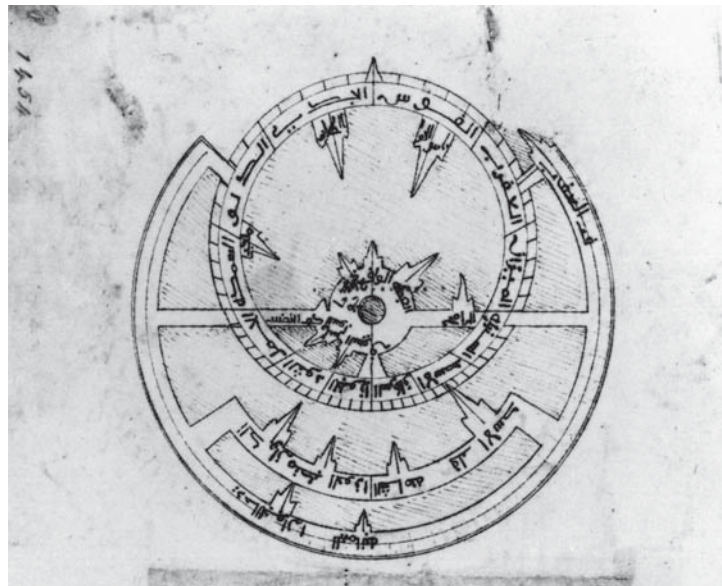



Fig. 1.2: The solitary rete of [Khafīf] (#2529). [Courtesy of the Museum of the History of Science, Oxford.]

Figs. 1.3a-b: The illustrations of an astrolabe by Khafīf executed in Florence in 1520 (#4030). [Courtesy of the Galleria degli Uffizi, Florence, and thanks to Professor George Saliba.]

Paper. Dimensions unknown. Drawings are apparently signed and dated (1520). Astrolabe is signed and undated.
Bibliography: Saliba, "Astrolabe by Khafīf". The drawings are also published in Nicholas Adams, ed., *Corpus of the Drawings of Antonio da Sangallo the Younger*, vol. 1, New York: Architectural Foundation, *ca*. 1991 (not seen).

These remarkable drawings were executed in 1520 by Antonio da Sangallo the Younger, the Florentine architect who built the greater part of St. Peter's in Rome. They were originally on a single folded sheet, now in two halves and inventorized as recto and verso. The mater with astrolabic markings (or, less likely, a single plate fitted in the mater), the rete and the back are depicted with remarkable care and thoroughness. Also an alidade, possibly original, and a nut and bolt, undoubtedly replacements, are featured.

The ensemble has been carefully investigated by George Saliba, who compared it with the two Oxford pieces (**1.1-2**). The drawing represents a genuine astrolabe by Khafīf, now lost, and the rete is not identical to the solitary Oxford rete. The original instrument was fixed up by an Andalusī astrolabist long before it came to Italy—various features on the back provide clear evidence of this. (This was also recognized by Saliba.)

The throne is slightly different from that on **1.1**. It has a broad raised base at the middle of which a small lobe leads to a larger one on each side of a smaller central lobe at the centre of which the suspensory apparatus is attached. There are relatively large holes at the middle of each of the larger lobes. There is a small shackle with a circular part fitting over the central lobe and the very small saddle fitting over a circular ring. The scale of the rim is divided 5°/1°-5° and there is a peg at the bottom. There are additional arguments in European numerals on the scale—see below. The mater bears astrolabic markings—see below.

The rete is identical to those on **1.1-2** but has *mankib* instead of *mankib al-faras* (as on both) and *dhanab al-dajāja* (as on the former, the latter has only *al-dajāja*). The stars are listed under **1.1** above. The latter is to be taken as definitive evidence that the rete depicted here is not the solitary rete **1.2**. The variant *al-samaka* is used for Pisces as on both **1.1-2**. No handle is depicted.

The mater bears altitude circles for each 6° labelled once inside the outer base circle and up the meridian to the zenith. The curves for the seasonal hours are also labelled once in *abjad* notation, and the ends of the horizon are marked *al-maghrib* and *al-mashriq*. The markings serve (*li-ʿarḍ — sāʿātuhu —*):

30° 14 [+2]

and the length of longest daylight is based on obliquity 23;51° (compare the identical value given on a plate of another Abbasid astrolabe (**2** below), there for latitude 29;55°). This plate for the third climate would have served Fustat, although the latitude there was taken as 29;55° on contemporaneous astrolabes (see again **2**). The Italian text—see below—indicates that there were originally three plates, but unfortunately gives no more information.

The back has three sets of markings, the first original, the second added in al-Andalus, and the third either recently added on the instrument or added by Antonio on his drawing. Original are the altitude scale on the upper left, divided 5°/1°-5°, and the inscription on the rim of the upper right in *kūfī* script (compare the engraving on the throne of **1.1**):

صنعه خفيف غلام علي بن عيسى

"Constructed by (*ṣanaʿahu*) Khafīf, apprentice of ʿAlī ibn ʿĪsā."

The horizontal and vertical base diameters, as well as the three concentric circles all around the rim which bound the altitude scale and the inscription, are original. Also possibly original is the shadow square in the lower right, opposite the altitude scale; its scales are divided 2/1 (base 12) and are unlabelled, being marked simply *al-ẓill al-mabsūṭ* and *al-ẓill al-mankūs*. Its diagonal is slightly more than one-half of the radius of the back; had it been longer, the Andalusī would have had problems inserting the additional scales. On the other hand, the shadow-scale may have been added by the Andalusī.

The alidade is rectilinear and has a semicircular protrusion at the middle. The ends are tapered, and the vanes have one hole each.

Additional markings

First set. The concentric calendrical and solar scales cannot be original, although they appear to fit perfectly between the innermost of the outer three circles and the corner of the shadow square. (The later additions to the Brescia Byzantine astrolabe (**Fig. XIIIa-4b**) and Abbasid astrolabe in Florence (**6**) were less successful.) The calendrical scale is on the outside (unusual, if not unique?), and is divided $5^d/1^d$ within each month, all having 30 days (unusual). The names of the months are written:

yxyr fbryr m'rs 'xrxl m'yh ywnbh ywlyh 'ghst stnbr 'ktwbr nwnbr djnbr

The names of the zodiacal signs are standard but for the tell-tale *al-tawʾamān* and *al-ʿadhrāʾ*, which are attested on various Andalusī and Maghribi astrolabes (see, for example, §1.3.6a-b of the Frankfurt catalogue). The script is awkward and seems to be a copy of an Andalusī *kūfī*. The equinox is at March 15, which is typical of early Andalusī astrolabes.

Second set: The arguments 5—10—5—... (1)20 have been added to the scale on the rim of the mater in Renaissance numerals. On the altitude scale on the back the arguments 5—10—...—90 have been added in the same way.

Replacement parts

The nut and bolt are clearly replacements.

Text on the drawing (mainly after Scaglia and Saliba):

Between the back and the mater: *strolabio egyptizio da ritto et da verso*, (an) Egyptian (*sic*) astrolabe from the front and back.

Under the back: *da questa banda sta lo alidada,* the alidade is on this side.

Under the mater: *da questa banda si incapassa le tavole luna sopra all altra cioe tre tavole e di poi la ragna qui retro disegniate*, the plates on this side are assembled one above the other, that is, three plates, with the rete then draughted on the other side of this sheet.

On the alidade und beneath it: *alidada*; *gli busi dello alidada colli quali sintraguarda sono tutti dal mezo in la come sta segniata*, alidade; the holes of the alidade (through) which one looks all appear from the centre to the end, as indicated.

Next to the nut and bolt: *vite femina; asse a vite quale se cingie le tavole et la ragna et lo alidado*, female screw (nut); screw with which the plates, rete and alidade are held together.

2 An undated astrolabe by Aḥmad ibn Khalaf

International Instrument Checklist #99.
Paris, Bibliothèque Nationale, Département des Cartes et Plans: inv. no. Ge. A.324. Acquired in Cairo by the Arabist François Jomard *ca*. 1835, and presented to what was then the Bibliothèque royale. Brass. Diameter: 129 mm.
Bibliography: Sédillot-*fils* made a mess of the readings on the plates (*Mémoire*, pp. 172-174), and his misinterpretations were repeated in Gunther, *Astrolabes*, I, p. 230 (no. 99) (see pl. LII for the front and back and p. 232 for the star list). Gunther also confused da Schio's pronouncements on **8.1** (#100), the next piece in his book, applying them to this piece and designating it "type of A.D. 950". The information on the plates in *London SM 1976 Exhibition Catalogue*, p. 99, is also inaccurate, but Destombes, "Astrolabe carolingien", p. 11, gives the correct latitudes. See Kunitzsch, *Arabische Sternnamen in Europa*, p. 60, on the dating. On the star-positions see Stautz, *Mathematisch-astronomische Darstellungen auf mittelalterlichen Instrumenten*, pp. 46-47 (no details).

This astrolabe was made by Aḥmad ibn Khalaf for Jaʿfar, son of (the Abbasid Caliph) al-Muktafī bi-'llāh. The instrument is undated but the Caliph ruled from 289 to 295 H [= 902-908], and his son lived from 294 to 377 H [= 906-987]. This Jaʿfar was much involved in the mathematical sciences and their bibliography.[62] Ibn al-Nadīm used a work by him as a source of his information. Also he collected some records of earlier observations, one of which, dealing with sunspots sighted during the year 840, survives. Furthermore, an Abbasid astronomer-mathematician dedicated a book on surds to Jaʿfar. Thus it was highly appropriate that one of the leading instrument-makers of Baghdad should make for him an astrolabe.

I have no decent photos of this astrolabe: see **Fig. 2**. The throne is simple, with four lobes and one large hole on each side, and the suspensory apparatus with trowel-shaped arms attached to a smaller hole at the middle appears to be original. The rim of the mater is divided 5°/1°-5° (without hundreds). The mater bears no markings.

The rete has an equinoctial bar that is rectilinear and the lower equatorial bar has three supports with a handle attached to the middle one. On the ecliptic each sign is divided into 6°-intervals, and *al-samaka* is used for Pisces. Regulus is at Leo 15°. The rete is marked for the following 17 stars:

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[62] See Suter, *MAA*, no. 142; Sezgin, *GAS*, V, p. 305, and VI, p. 61; and Goldstein, "Medieval Transit Reports", pp. 51-52.

Fig. 2: An old photo of the astrolabe of Aḥmad ibn Khalaf (#99). Maybe some time in the Third Millennium museums will stop taking photos of astrolabes with the alidades on the front. The BNF was unwilling to prepare new images without a great deal of hassle, offering me instead a new copy of this photograph; it was cheaper to make a copy in Frankfurt. Alas, no illustrations of the plates are available. [From Gunther, *Astrolabes*, pl. LII, opposite p. 230.]

al-ghūl
al-dabarān
rijl al-jabbār
al-ʿayyūq
mankib al-jabbār
al-yamāniya

---

al-shaʾāmiya
qalb al-asad

---

al-rāmiḥ
al-fakka
[qal]b al-ʿaqrab
raʾs al-ḥawwāʾ
al-wāqiʿ
nasr al-ṭāʾir [*sic*]
al-ridf
mankib
al-khaḍīb

The star-positions are, with one exception, accurate. The pointer for *qalb al-ʿaqrab* is blunt, as if broken, but in fact is too long (Stautz).

The four plates are marked with altitude circles for each 6° of altitude. Two of these are associated with specific localities; two others lack values of the length of maximum daylight. This information may be summarized as follows:

1a	21°	Mecca	$13;18^{h}$ [a]	[0]
1b	24	-	13;30	[-1]
2a	29;55 [b]	*Miṣr* [c]	14	[+2]
2b	31	-	14; 6	[+3]
3a	34	-	-	
3b	36	-	-	
4a	37	Ḥarrān	14;36	[0]
4b	39	-	15	[+12 (!!)]

a The original value for the minutes has been obliterated, but the 18 is in the original hand

b 55 without dots; could be read as 15; however, 29;55° is confirmed by the associated length of daylight

c Cairo was founded in 969; *Miṣr* here refers to Fustat

The plates for latitudes 34° and 36° also bear azimuth circles above the horizon for each 10°, engraved up to altitude 84°. The arguments form a shape resembling a rounded M-shaped arch.

This geographical information is not without interest. It is not clear why there is no plate for the latitude of Baghdad; I do not recall that one plate is missing. The maximum daylight values for latitudes 21° and 37° are accurate only for obliquity 23;51°, and it appears that this parameter underlies the rest, which are, however, less carefully computed. For latitude 39° the longest daylight is only $14;48^{h}$ rather than 15^{h} as stated; it cannot be that the minutes of latitude were omitted by mistake since the latitude of the fifth climate is closer to 41°.

We should consider the distinctive latitude 29;55° for *Miṣr* in the context of the other values that were used before and after. The Arabic *Miṣr* can refer to any of Egypt, Fustat or Cairo, depending on the date and the context.[63]

Excursus: The latitude of Fustat-Cairo

In the following, I have mainly relied on Kennedy & Kennedy, *Islamic Geographical Coordinates*, pp. 121-122 (Fustat) and 111-112 ("Egypt"), and I use the their three-letter abbreviations to denote their sources.

The value 30;0° was used for "Babylon in Egypt" by Ptolemy (PTO), and was adopted by

[63] The new city of al-Qāhira (Cairo) was founded in the year 969, but astrolabists thereafter (for example, in 11th-century al-Andalus) continued to use the expression *Miṣr*, meaning *Miṣr al-Qāhira*, or Cairo-Fustat. See further the article "Miṣr" in EI_2, especially pp. 146-147.

al-Khwārizmī (KHU) and al-Battānī (BAT), as well as Ibn Yūnus (YUN), who relied heavily on al-Khwārizmī.

Ibn Yūnus stated that the generally-accepted value was 29°. From other sources, we know that this value 29;0° is associated with the late-8th-century Egyptian astrologer Māshāʾallāh (MSH YAQ). This is the reason why we cannot dismiss 29;15° as a copyist's error for 29;55° (see below).

Ibn Yūnus has left us a delightful account of the way in which he demonstrated to two other astronomers that the latitude of Fustat was 30°, rather than 29°. Both these men, Ibn al-Ṭahhān and al-Labbānī had measured it and convinced themselves that it was 29°. On the day of the summer solstice, using an astrolabe made by Ḥāmid ibn ʿAlī al-Wāsiṭī (see **8**), Ibn Yūnus showed them that the solar altitude was a little over 53° in the prime vertical and 83;35° in the meridian. Both these values implied a latitude of 30°. At the winter solstice he showed them that the shadow of a vertical gnomon confirmed that value. Ibn al-Ṭahhān then realized why the the shadow trace on the sundial he had erected in a mosque in the suburb of al-Qarāfa failed to correspond to the markings he had made on it for latitude 29°.[64]

On the astrolabe of Aḥmad ibn Khalaf the latitude of *Miṣr* can be interpreted 29;15° or 29;55°. The two values are written identically if dots are omitted for the consonants representing 10 (two dots below the carrier) and 50 (one dot above), although convention dictates that the reading would be 15 if there is no dot.[65] Now we find the distinctive value 29;55° for the first time in a set of tables attributed to al-Khwārizmī (KHZ), but the reading 29;15° is recorded in a manuscript of the *Geography* of Suhrāb (SUH). Or was the original value 29;15° and the better value 29;55° the result of a fortuitous misreading?

The value 29;55° bears the hallmarks of having been computed rather than observed, that is, derived from the associated maximum daylight for the middle of the third climate, that is 14^h, and an assumed value of the obliquity. But it was inaccurately computed (by medieval Muslim standards), and it is also several minutes too low for Fustat (modern Cairo is at latitude 30°3′).

This notwithstanding 29;55° occurs in several Islamic geographical tables as the latitude of Egypt / Fustat / Cairo. Thus, for example, it was used for Cairo by the 13th-century astronomer al-Marrākushī (**II-6.7**), but only for the numerical examples in his major work on spherical astronomy and instrumentation. For his tables in this work, he used the more accurate value, 30;0°, which was most widely accepted in later times.

The back of the astrolabe is divided into four quadrants by two diameters but bears no markings other than scales from 0° to 90° on the rims of the upper two (the circles are continued below the horizontal diameter). The inscription at the middle of the right-hand scale continues with the dedication on the throne:

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[64] Summarized in King, *Ibn Yūnus*, §III-11.6 on pp. 101-102. For a complete translation see Schoy, "Arabische Methode ... ", pp. 126-128.

[65] See the text to n. 66 below for this problem as it relates to letters.

صنعه أحمد بن خلف | لجعفر بن المكتفي بالله

"Constructed by Aḥmad ibn Khalaf // for Jaʿfar ibn al-Muktafī bi-'llāh".

Replacement parts
The broad rectilinear alidade, horse and pin appear to be replacements, and the horse is broken. Note, however, that the alidade (not necessarily original) that once graced the Kuwait astrolabe of Nasṭūlus (**3.1**) was equally ungainly.

3 Nasṭūlus and his two surviving astrolabes

> "Contradiction est une mauvaise marque de vérité. Plusieurs choses certaines sont contredites. Plusieurs fausses passent sans contradiction. Ni la contradiction n'est marque de fausseté ni l'incontradiction n'est marque de vérité." Blaise Pascal, *Pensées*, cited in Y. Maeyama, *Studies*, p. 526.

We shall here discuss the oldest dated Islamic astrolabe. Whilst several earlier Abbasid instruments survive, they are undated. In any case, it should be borne in mind that Muslims had been making astrolabes for about 150 years before this one was made. The maker signed himself simply as Xasṭūlus, where *x* denotes a letter that can be read as *bāʾ* or *nūn* (or *tāʾ* or *thāʾ* or *yāʾ*).[66] An astrolabe mater signed in the same way but undated is preserved in Cairo.

The maker's full name—Muḥammad ibn ʿAbdallāh known as B/Nasṭūlus—is found in the manuscript sources, and in 1974 Alain Brieux and Francis Maddison proposed the reading Basṭūlus, derived from Greek *apostolos*.[67] In 1978 Fuat Sezgin, in the astronomy volume of his monumental *Geschichte des arabischen Schrifttums*, presented all of the bio-bibliographical information available on "Nasṭūlus (vielleicht: Basṭūlus?)", the dubious alternative inspired by the thesis of Brieux and Maddison.[68] Also in 1978, I presented the evidence for the reading Nasṭūlus.[69] The most striking was that *apostolos* in any form would be a singularly inappropriate appellation for a Muslim named Muḥammad ibn ʿAbdallāh, the same name as the Prophet (*apostolos = rasūl*) of Islam. In 1983, Paul Kunitzsch and I showed that Nasṭūlus was an acceptable variant of the attested Christian Arab name Nasṭūrus.[70] This notwithstanding, the erroneous name Basṭūlus continues to be used by the Kuwait Museum. Worse still, our man has been baptized as "Muḥammad Basṭūlus Asṭurlābī" in the new bio-bibliographical source book for Islamic science by Boris Rosenfeld and Ekmeleddin İhsanoğlu, with the explanation: "Basṭūlus is a distortion of the word Apostolos, Nasṭūlus is a further distortion of this name, differing from Basṭūlus only by a dot over the first letter."[71] There is now no way to arrest the propagation of this mis-information.

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[66] See the text to n. 65 above for this problem as it relates to numbers.
[67] Brieux & Maddison, "Basṭūlus or Nasṭūlus?".
[68] Sezgin, *GAS*, VI, pp. 178-179 and 288.
[69] King, "Nasṭūlus/Basṭūlus".
[70] King & Kunitzsch, "Nasṭūlus".
[71] Rosenfeld & İhsanoğlu, *MAIC*, p. 69 (no. 152), taken over from Matvievskaya & Rosenfeld, *MAMS*, II, p. 126 (no. 96a). Inevitably, our man is named Basṭūlus in the new Meshed "edition" of al-Bīrūnī's *Istīʿāb* (p. 122).

Nasṭūlus is also known to have devised several varieties of astrolabe and eclipse-calculators. Ibn al-Nadīm mentions Nasṭūlus as one of the leading astrolabists of his time, and it is clear that he worked in Baghdad. N/Basṭūlus is mentioned by the 10th-century bibliographer Ibn al-Nadīm, and already Gustav Flügel, who edited his *Fihrist* in 1871, had problems with the name, which is corrupt in all the manuscripts.[72] al-Bīrūnī mentions N/Basṭūlus in his own work on the construction of different kinds of astrolabes entitled *al-Istīʿāb*. al-Bīrūnī's section on this subject was first discussed by Joseph Frank and Eilhard Wiedemann in 1920.[73] al-Bīrūnī's discussion was in turn used by the 13th-century Cairo astronomer Abū ʿAlī al-Marrākushī in his *summa* entitled *Jāmiʿ al-mabādiʾ wa-'l-ghāyāt*. al-Marrākushī's section on unusual astrolabes was first discussed by L. A. Sédillot in 1844.[74]

A "new" source for the history of the astrolabe in Islam, which has yet to be studied properly, is the treatise on the construction of unusual astrolabes by the 10th-century mathematician, astronomer, and astrologer Aḥmad ibn Muḥammad ibn ʿAbd al-Jalīl al-Sijzī.[75] His treatise on the astrolabe exists in a unique copy MS Istanbul Topkapi A3342, fols. 123r-153v and 114r-122v, copied in Damascus in 634 H [= 1236-37] and discovered by Max Krause in 1932.[76] It was the main source of al-Bīrūnī, and hence, indirectly, of al-Marrākushī. al-Sijzī's treatise is far more detailed than both, and shows that we should not dismiss these astrolabes, as did Henri Michel, as "une coquetterie géométrique".[77]

al-Sijzī in the section of his treatise dealing with the astrolabe called *al-musarṭan* with a crab-shaped ecliptic on the rete,[78] states that the first person to design such an instrument was "Muḥammad ibn ʿAbdallāh, known as Nasṭūlus". He adds that Nasṭūlus "invented the hours drawn on the face of the alidade and the operation with the azimuth on the back of the astrolabe". al-Bīrūnī in his treatise on shadows, *Ifrād al-maqāl fī amr al-ẓilāl*, describes alidades marked with graduations for the hours, but does not mention N/Basṭūlus in this connection.[79] The relevant passage in al-Sijzī's treatise translates (fol. 150r):

> "The *musarṭan* astrolabe, which is (also called) *al-mushajjar*—fitted with designs of plants (?)—is better and more beautiful than all other kinds of astrolabes. I think that Muḥammad ibn ʿAbdallāh known as Nasṭūlus was the first to construct this. He was skillful and clever in devising astronomical instruments, and had a good hand for making them. He also invented the hours drawn on the face of the alidade and the operation with the azimuth on the back of the astrolabe."

al-Bīrūnī in the *Istīʿāb* repeats al-Sijzī's statement about N/Basṭūlus being the first to design a *musarṭan* astrolabe but without the additional biographical information (MS London B.L. Or. 5593, fol. 36v, copied about 700 H [= 1300]):[80]

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[72] Ibn al-Nadīm, *al-Fihrist*, p. 26, notes to p. 285 of Flügel's edition.
[73] Frank, *Zur Geschichte des Astrolabs*, pp. 9-10; and Wiedemann, *Aufsätze*, II, pp. 516-541.
[74] Sédillot-*fils*, *Matériaux*, pp. 181-183.
[75] Sezgin, *GAS*, V, pp. 329-334; VI, pp. 224-226; and VII, pp. 177-182.
[76] Krause, "Stambuler Handschriften", pp. 468-469 (no. 185).
[77] Michel, *Traité de l'astrolabe*, p. 69.
[78] Frank, *Zur Geschichte des Astrolabs*, pp. 13-17; Michel, *Traité de l'astrolabe*, pp. 69-71; and Charette, *Mamluk Instrumentation*, p. 69.
[79] al-Bīrūnī, *Shadows*, transl., I, pp. 238-240, and II, pp. 149-150.
[80] Wiedemann, "Instrument … … ", p. 13; and Frank, *Zur Geschichte des Astrolabs*, p. 13.

> "The *musarṭan* astrolabe is composed of these two combinations (of the northern and southern astrolabe projections), and is (the most) famous amongst the other (such) combinations. Its invention is attributed to Basṭūlus. Abū Saʿīd Aḥmad ibn Muḥammad ibn ʿAbd al-Jalīl wrote a book on the rules for mixing the northern astrolabe with the southern one ... ."

However, elsewhere in the *Istīʿāb* al-Bīrūnī mentions N/Basṭūlus as one of the persons who worked on instruments for determining eclipses (MS London B.L. Or. 5593, fol. 84v):[81]

> " ... The construction of the eclipse plate. (Both) Basṭūlus al-Asṭurlābī and al-Ḥasan ibn Muḥammad al-Ādamī were concerned with the eclipse plate, and it was perfected by ʿUṭārid ibn Muḥammad al-Ḥāsib ... ."

This passage is not found in the treatise of al-Sijzī. The name in the London manuscript of the *Istīʿāb* is written Basṭūlus, and, according to Wiedemann, the reading is Basṭūlus in MS Berlin Ahlwardt 5796 of the *Istīʿāb* and Nasṭūlus in MS Leiden Universiteitsbibliotheek Or. 591. al-Marrākushī does not mention N/Basṭūlus either in his section on the *musarṭan* astrolabe or in his section on eclipse computers.

Another treatise on the astrolabe, which differs from the *Istīʿāb* but is also based on the treatise of al-Sijzī and is attributed to al-Bīrūnī, states (MS Paris B.N.F. ar. 2498, fol. 6r):[82]

> "Abū Saʿīd Aḥmad ibn Muḥammad ibn ʿAbd al-Jalīl al-Sijzī followed the example of N/Basṭūlus in inventing numerous types of (astrolabes) ... ."

Thus the earliest available textual evidence gives the name as "Muḥammad ibn ʿAbdallah, known as Nasṭūlus". Fuat Sezgin, however, lists him as Muḥammad ibn Muḥammad, known as Nasṭūlus.[83] In any case, it is clear that the man was a Muslim.

In 1983, during the official opening of the new Kuwait Museum of Islamic Art, which institution had purchased the dated astrolabe of Nasṭūlus from Alain Brieux, I discussed the curious name with the late Dr. Martin Hinds of Cambridge University. He suggested that it might refer to the Christian sect of the Nestorians, and Paul Kunitzsch was able to confirm this. The name Nasṭūrus was a name actually in use in 10th-century Egypt. One ʿĪsā ibn Nasṭūrus was vizier to the Fatimid caliph al-ʿAzīz, for a short time only (385-386 H [= 995-996]) before, under that caliph's successor, al-Ḥākim, he was put to death, apparently in the same year 386 H [= 996].[84] Furthermore, there was also Zurʿa ibn ʿĪsā ibn Nasṭūrus, apparently a son of the preceding, and also a Fatimid vizier.[85] Here we have a well-documented name, Nasṭūrus, used by Christian men in Egypt in the 10th century. It seems clear, at least to a couple of Arabists with a background in comparative Semitic philology, that the name Nasṭūlus, on the two astrolabes and in the sources cited above, is just another form of the name Nasṭūrus, changed for ease of pronunciation from *-rus* to *-lus* (by a sort of "dissimilation").[86] This would mean

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[81] al-Bīrūnī's eclipse computer is described in Wiedemann, "Instrument … … ", and now Hill "al-Bīrūnī's Mechanical Calendar".

[82] Sezgin *GAS*, VI, p. 269 (no. 11); *Cairo ENL Survey*, no. B78 (4.3.5).

[83] Sezgin, *GAS*, VI, pp. 178-179.

[84] For references, see EI_2, I, pp. 823b and 824b (*sub* al-ʿAzīz); II, p. 858a (*sub* Fatimids); and III, p. 77a (*sub* al-Ḥākim).

[85] EI_2, II, p. 858a (*sub* Fatimids).

[86] For the sound shift from "r" to "l" in Arabic and other Semitic languages see Brockelmann, *Grundriss der vergleichenden Grammatik der semitischen Sprachen*, I, pp. 221 (§84 b, 1α), 223 (§84c, and §84d, 1β), and 228-229 (§84m, 1β).

that *Nasṭūlus* was a normal and acceptable form parallel to *Nasṭūrus*. I was unable to find any name Nasṭūrus or Nasṭūlus in Georg Graf's monumental *Geschichte der christlichen arabischen Literatur* (1944-51). The closest I came was a family name Busturus in 19th-century Lebanon.[86a] The name is unpointed because Graf was citing French bibliographical works: presumably, it was written Busṭūrus in Arabic. With this piece of evidence, we have come a complete circle; certainly, we have not advanced.

3.1 An astrolabe dated 315 H

International Instrument Checklist #3501.
Kuwait, Islamic Archaeological Museum (Dār al-Āthār al-Islāmiyya), inv. no. LNS 36M. Purchased in the 1970s from Alain Brieux, Paris, who is quoted by G. Ifrah as having said that it once belonged to King Farouq of Egypt.[87] Exhibited at the "Festival of Islam" in London, 1976, and at a series of museums in Europe and the US between August, 1990, and May, 1994. (This instrument was not stolen in the autumn of 1990 because it was on loan in the U.S.)
Brass. Diameter: 173 mm. Thickness: 4 mm.
Bibliography: *London SM 1976 Exhibition Catalogue* (unpublished), pp. 99-100; Brieux & Maddison, "Basṭūlus or Nasṭūlus?"; King, "Nasṭūlus/Basṭūlus"; King & Kunitzsch, "Nasṭūlus"; and the following Kuwait catalogues: *NM 1983*, p. 39 (with colour photo of front); *NM 1984*, pp. 8-9; *DAI 1989*, p. 15 (also colour illustration on front cover). On the star-positions see Stautz, *Mathematisch-astronomische Darstellungen auf mittelalterlichen Instrumenten*, pp. 46-47 (no details).

The throne and rim are cast as one, and to this the back is rivetted in several places. The throne has three shallow lobes and a small hole on each side close to the central one, and the suspensory apparatus is a neat shackle with trowel-shaped arms and a circular ring. The scale on the rim is divided 5°/1°-5° (without tens and hundreds), and the mater is devoid of markings except for a peg to hold the plates at 0.66 of the radius below the centre.

The rete has a rectilinear equinoctial bar, its upper side representing the axis. There is a / \ -shaped support below the rather large central disc. On the right-hand support of the lower equatorial bar (which lies outside the equator) is a handle. There is a small hole on the pointer for *al-wāqiʿ*, also found on **5**, **6**, **9**, **10**, and apparently intended to represent the pole of the ecliptic. (I know of no textual references to such markings, though see **Fig. 10.6a**.) The star-pointers are dagger-shaped, and the position of Regulus is about Leo 13°. On the ecliptic the signs are divided into unlabelled 6°-intervals and *al-samaka* is used for Pisces. The 17 stars represented are as follows:

raʾs al-ghūl	*al-simāk al-rāmiḥ*	
ʿayn al-thawr	*munīr al-fakka*	
al-ʿayyūq	*qalb al-ʿaqrab*	
rijl al-jawzāʾ	*raʾs al-ḥawwāʾ*	
yad al-jawzāʾ	———————	
al-yamāniya	*al-wāqiʿ*	pointer has small hole

[86a] Graf, *GCAL*, IV, pp. 294, 303, 314..
[87] Ifrah, *Histoire des chiffres*, I, 589, Engl. transl. p. 287.

a

d

b

Figs. 3.1a-d: (a-b) The front and back of the Kuwait astrolabe of Nasṭūlus (#3501).
(c) The inscription on the earliest dated Islamic astrolabe.
(d) The plate for latitude 33° (serving Baghdad) in the astrolabe of Nasṭūlus.
[Photos courtesy of the Dār al-Āthār al-Islāmiyya, Kuwait.]

c

———————	*al-nasr al-ṭāʾir*
al-shaʾāmiya	*al-ridf*
qalb al-asad	*mankib al-faras*
———————	*al-kaff al-khaḍīb*

The star-positions are astoundingly accurate (Stautz).

The single plate bears altitude circles for each 6° (and *no* azimuth circles) for the following latitudes (*ʿarḍ* — *sāʿātuhu* —):

1a	33°	14;13^{h}	[0]
1b	36	14;30	[0]

The values of the lengths of longest day are correct only for the Ptolemaic value of the obliquity. The altitude arguments are labelled not only between the equator and Capricorn but also between radial marks on the outer rim of the plate, as are the seasonal hours, so that at least some of these are always visible at the open part of the circumference of the rete. This feature is otherwise attested only on the instrument of the brothers al-Iṣfahānī (see **10**). The latitudes represented on the plate would serve Baghdad (and Damascus), and Mosul (and Rayy) or, more probably, the middle of the fourth climate. There is no room for any more plates.

The back of the throne bears the inscription:

صنعه بسطولس | سنة شيه

"Constructed by Xasṭūlus in the year 315 (Hijra) [= 927/28]."

Below are four altitude scales divided 5°/1°-5° and there is a shadow-scale (to base 12) divided 5/1 and labelled for each 5 units up to 45 inside the altitude scale on the lower right. There are no other markings on the back (apart from the shadow of the alidade).

The original alidade, horse and pin are missing but the surface on the back has been discoloured by a rectilinear alidade of unduly large width (1.8 cm)—compare **2**.

3.2 An undated astrolabe mater with a gazetteer (with various Mamluk Egyptian additions)

International Instrument Checklist #1130 (dated 714 H) = #4023.
Cairo, Museum of Islamic Art: 15351. Formerly in the Harari Collection (no. 400). Earlier provenance?
Brass (with reddish patches showing on the back). Diameter: 130 mm. Thickness: 4 mm.
Bibliography: Muṣaylaḥī, *al-Asṭurlāb*, p. 56, and pls. 4-6 (signature and front of mater only); Kunitzsch & King, "Nasṭūlus", p. 343, n. 1 (maker identified by Alain Brieux).

The throne is low, raised, with three lobes on each side that look as though they have been filed down, and it is pierced by three holes, the middle one smaller than the other two. The suspensory apparatus that would have been attached to the middle hole is missing. The scale on the rim of the front of the mater has been almost erased, apparently by use: it is divided 5°/1°-5° (without hundreds or tens). The back is separate from the rim, attached by rivets of which only one is visible. There is a later inscription on the front of the throne—see below.

The mater bears a gazetteer, unique of its kind on early instruments, and not known from any textual sources.[88] The information contained in it is therefore of considerable historical interest—see below. There is a pin at the bottom of the inside of the mater to hold the plates.

On the back of the throne is the simple statement:

صنعه بسطولس

"Constructed by Xasṭūlus."

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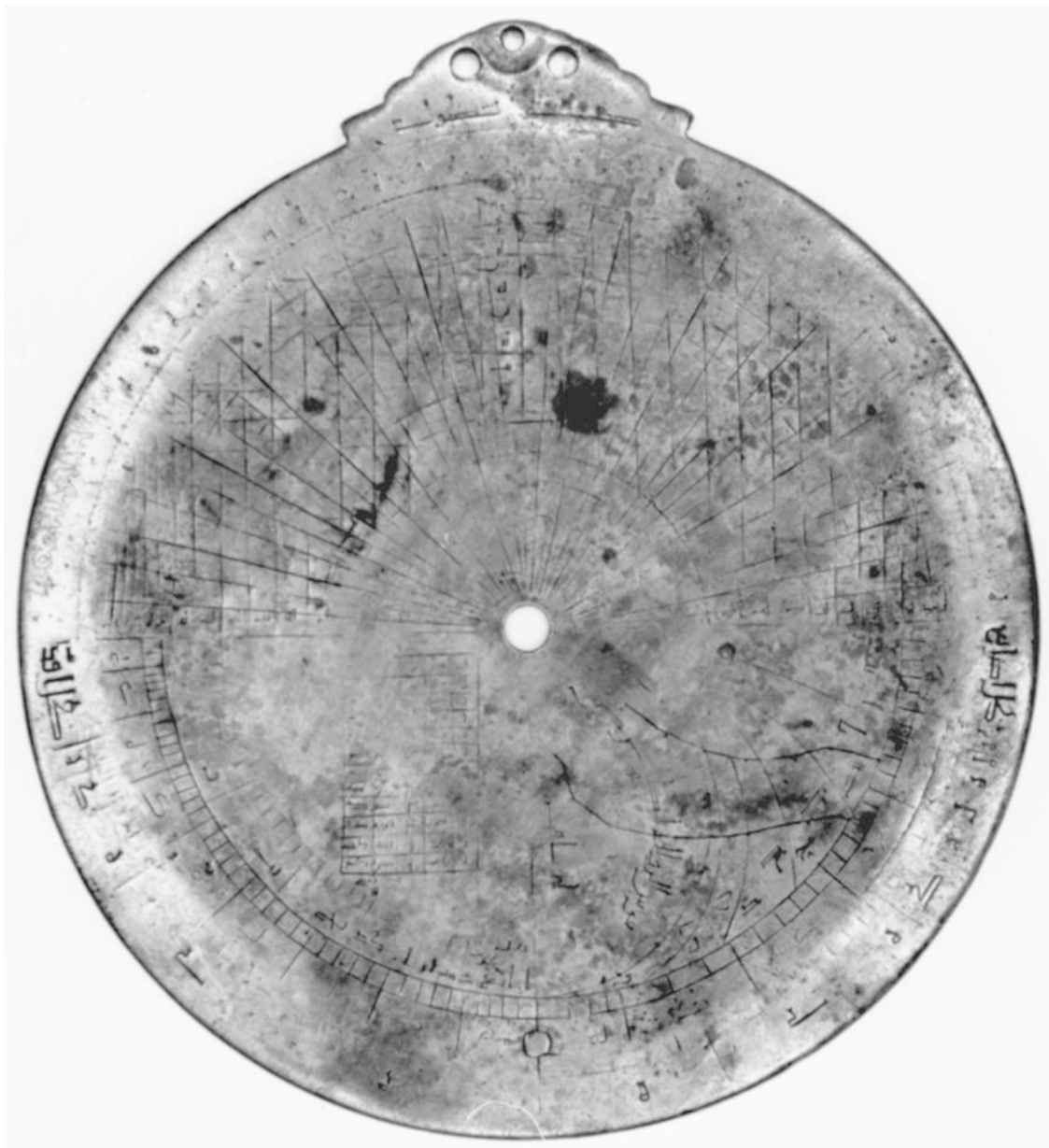
[88] This table is already edited in King, "Geography of Astrolabes", pp. 29-31, but is not included in the new version in **XVI**.

Figs. 3.2a-b: (a) The mater with gazetteer on the Cairo astrolabe of Nasṭūlus (#1130 = #4023). (b) The later Mamluk inscription on the front of the throne. [All photos courtesy of the late Alain Brieux.]

Figs. 3.2c-d: (c) The back of the Cairo mater of Nasṭūlus (#1130 = #4023), with later horary markings for the latitude of Cairo and a table for the Coptic calendar. (d) The maker's signature on the back of the throne.

There are two altitude scales divided 5°/1°-5°, both badly worn. The two upper quadrants bear a double trigonometrical grid with radii for each 5° and both horizontal and vertical parallels for each 5 units. There is a dotted semicircle with radius 24 units for finding the solar declination. The arguments 5—10—...—60 are written along the horizontal and vertical axes. On the lower right rim there is a shadow-scale (base 12) divided 5/1-5 up to 50 and marked *ẓill al-aṣābiʿ*, and inside this is an unmarked solar declination scale divided 5/1-5, the arguments at the end being written 20—23—35. This indicates that Nasṭūlus favoured 23;35° for the obliquity. Inside these scales is a universal horary quadrant with the midday curve marked *qaws al-zawāl li-kull ʿarḍ āfāqiyya*. On the lower left rim there is a badly-worn shadow-scale marked *ẓill al-aqdām*, and inside this there is an unmarked scale for the altitude of the sun at the *ʿaṣr*, divided 5°/1°-5° up to 45°. Inside this is a second scale for the *aṣābīʿ*, to which has been added the word *mukarrar*, "repeated". The other markings are later additions—see below.

There is no alidade.

The gazetteer

The localities and their latitudes, clockwise from the top, are listed below. The single-letter abbreviations for sources listed below are used instead of the three-letter ones used in Kennedy & Kennedy, *Islamic Geographical Coordinates*. For more details, the reader must consult the Kennedys' publication. Since the majority of the latitudes presented by Nasṭūlus agree with what one could expect from the geographical table of al-Khwārizmī, my main task has been to find possible sources for those that do not. The symbol ∅ indicates that there is no value in source K (see below). Values that round to those given by Nasṭūlus (he appears to have favoured rounding 30′ downwards) and which *may* have been used by him are printed in bold font. Entries marked ⊕ are discussed further in the notes after the tables. Particularly problematic entries are boxed.

Symbol	Source	
A	ATH	The 11th(?)-century Iranian table labelled *Kitāb al-Aṭwāl wa-'l-ʿurūḍ* (clearly some entries in our table are derived from one of its early sources)
B	BAT	al-Battānī (*ca*. 910)
G	BAG	al-Baghdādī (*ca*. 1280), derived from B and related to Q
H	HAB	Ḥabash al-Ḥāsib (*ca*. 850)—see nos. 1 and 2 below
K	**KHU**	**al-Khwārizmī (*ca*. 825), the major source for our table**
K+	-	Variant readings of K (Kb: KHU BAT; Kh: KHU HON; Kr: RSM FID; Kz: KHZ)
M	MSH	Mashā'allāh (*ca*. 780), only for Egypt
P	PTO	Ptolemy, from which K is ultimately derived
Q	QBL	al-Dimyāṭī (Cairo, 12th(?) century), based on earlier sources, related to B and G
S	SUH	Suhrāb (Baghdad, 10th century), based on K
T	SAA	Ibn Saʿīd al-Maghribī (Maghrib, 13th century)
Y	YUN	Ibn Yūnus (Cairo, late 10th century), based mainly on K
Z	-	most or all (other) early sources (to *ca*. 950)

	Locality	φ	Comments
1	Medina	24°	K-Z-B 25;0°—H **24;0°**
2	Mecca	21	K-Z-H **21;0**
3	Tiflis	41	K Ø—Z 42;0 / 43;0
4	Qum	35	K-Z 35;40—B 36;0—A **34;45**
5	Nishapur	37	K **37;0**
6	Shustar	32	K Ø—A 31;30
7	Istakhr	32	K **32;0**
8	Farama	31	K-B 31;30—S **31;20**
9	Alexandria	31	K **31;5**
10	Ifriqiya	36	K Ø—B 31;0—⊕
11	Massisa	36	K **36;0**
12	Adana	35 (!)	K Ø—Z 36;45 / 36;50
13	Tarsus	36	K 36;55—S 37;35—Y **36;15—**⊕
14	Nihawand	34	K-Z 36;0—A **34;30**
15	Hulwan	34	K **34;0**
16	Baghdad	33	K **33;9**—Kz **33;0**—S **33;25**
17	Samarra	34	K **34;0**
18	Tikrit	34	K Ø—S 35;8—A **34;30**
19	Haditha	35	K 34;20 (Ana)—S 32;0 (al-H)—A 33;35 / 36;0—⊕
20	Mosul	35	K-Z **35;30**
21	Balad	36	K **36;20**
22	Erzerum	37	K Ø—Kr 39;15—A 41;0
23	Akhlat	37	K-Z 39;50
24	Mayyafariqin	37	K 37;55—Kh **37;15—**⊕
25	Amid	35	K Ø—Kb 37;52—S **34;40**—A 37;0
26	Tell Mawzan	37	K Ø—B-Q **37;0—**⊕
27	Raʾs al-ʿAyn	37	K **37;0**
28	Nisibin	36	K **36;0**
29	Hit	33	K **33;15**
30	Ana	34	K **34;20**
31	Qarqisiya	35	K **35;20**
32	Raqqa	36	K **36;0**
33	Damascus	33	K **33;0**
34	Edessa	37	K **36;40**
35	Harran	37	K **36;40**
36	Aleppo	34 (!)	K-S **34;30**—Kz 33;30—A 35;50
37	Manbij	35	K-Kz S **35;30**
38	Antioch	35	K 34;10—Kz 33;10—S **35;0**
39	Balis	36	K **36;0**
40	Homs	33	K-S 34;0—Kz **33;10**
41	Ascalon	33	K **33;0**
42	Tiberias	32	K **32;0**
43	Ramla	32	K-S 32;40—Kz **32;15**—A **32;10**
44	Jerusalem	32	K **32;0**
45	Gaza	32	K **32;0**
46	Fustat	30	K **30;0**
47	Tinnis	31	M **31;0**—K-Kr 31;40—S 32;30—A **30;40—**⊕
48	Kairouan	31	K-S-A 31;40—T **31;0—**⊕
49	Dinawar	34	K Ø—S **34;0**
50	Hamadan	35	K-Kz-S 36;0—A **35;0**
51	Qazwin	37	K **37;0**
52	Isfahan	34 (!)	K-Kr-Kz **34;30**—S **34;0**—A 32;40
53	Rayy	35	K-Kr-Kz 35;45—S-A 35;35
54	Ardebil	36	K Ø—S 40;0—A 38;0—G **36;0—**⊕
55	Kirman	30	K **30;0**
56	Shiraz	31 (!)	K-Kz 32;0—S **31;0**
57	Fars	32	P 33;20—K Ø—B **32;0—**⊕
58	Sus	32	K-B 34;0—A **32;15**
59	Ahwaz	32	K **32;0**
60	Basra	31	K **31;0**
61	Wasit	32	K **32;20**
62	Mada'in	32	K-S 33;0—B 35;55—A 33;10
63	Babil	32	P-B 35;0—K Ø—A **32;15**
64	Kufa	32	K-Kz **31;50**

Notes:
10 This is the first of two entries for provinces rather than cities (see also no. 32). K has 33;0° for Tunis and 31° for Kairouan (see no. 48).
13 ϕ: 36° could have been derived from 36;15° and the value we have for K is perhaps a copyist's error (see also no. 24).
19 There are three localities in Iraq called Haditha and the sources are confused. A is the first to distinguish between those on the Euphrates and Tigris, giving 33;35° and 36;0°, respectively (modern 34°9′ and 35°59′).
24 ϕ: 37° could have been derived from 37;15° and the value we have for K is perhaps a copyist's error (see also no. 13).
26 Only B and Q give this value, and the locality does not occur in any other source.
32 This is the second entry for a province (see no. 10), and al-Battani can hardly have been to Fars to measure its latitude.
47 KKrS have Tinnis in the Med, M is not bad for the 8th century, A is too low (modern 31°15′).
48 T is a 13th-century table, and perhaps this value occured in one of its sources.

Thus most of the entries are taken from al-Khwārizmī, rounded where necessary. The purpose of this table was to show which plates one should use in the various localities. Alas, no plates survive in this piece.

Later additions
An inscription on the front of the throne in *naskhī* script inlaid with silver translates:

برسم الطيبغا العزّى مستهل ذى القعدة سنة ٧١٤

"By order of al-Ṭaybughā al-ʿIzzī on the first day (*mustahill*) of
Dhu 'l-Qaʿda of the year 714 (Hijra) [= 1314/15]."

al-Ṭaybughā is a well-known scholar who authored several books on astronomical instruments.[89] We may assume that al-Ṭaybughā ordered a new rete and plates to be fitted to this mater, alas now lost. The other markings on the back were probably also added at his bidding, although they are not a total success.

Two rather unhappy sigmoid "curves" are engraved on the universal horary quadrant, starting some way out and ending at declination approximately 12;20° and 8;30° on the unmarked solar declination scale. These appear to represent the solar altitudes at midday and the beginning of the *ʿaṣr* prayer for latitude 30° (Cairo), but there is no associated solar longitude scale. On tables from medieval Cairo displaying the altitude of the sun at midday and the *ʿaṣr* see **II-4.3c** and **4.9**. It is not clear whether or not the second shadow-scale to base 12 is original.

Inside this shadow-square, there is a table, so badly worn that most of the entries are barely visible, let alone legible. The format (12 lines of entries and an additional note at the bottom) and the few visible entries indicate the nature of the table. All that I can see of the entries is:

l	*s*	7	-	-
l	*s*	8	-	-
l	*s*	1	-	-
...				

[89] Brockelmann, *GAL*, II, p. 135, and SII, p. 167; Azzawi, *Astronomy in Iraq*, pp. 171-172; and *Cairo ENL Survey*, no. C53. His treatise on archery is published as *Saracen Archery* … by Derek Latham and W.F. Paterson, London, 1970.

[*l*]	*s*	3	*Bashans*	20
[*l*]	*s*	4	*Baʾūna*	21
l	*s*	?	*Abīb*	22
l	*s*	?	*Misrā*	23

In the lower left can be read *nasī* (for the five intercalary days) and then a "5" (?), which is unrelated to the purpose of the table. The numerals are written in Hindu-Arabic numeral forms, and the letters in a rough *naskhī* script. This table may be compared with similar ones on the 13th-century Cairene astrolabes (from §1.5.8-9 of the Frankfurt catalogue), although some problems remain.

Excursus:
A comparable table occurs on two 13th-century Egyptian instruments with both Arabic and Coptic inscriptions (**Figs. 3.2e-f**). It is the numerals that are in cumbersome notation of the Coptic functionaries.[90]

#4036 An astrolabe with silver and gold inlay by Ḥasan ibn ʿUmar al-Naqqāsh dated 681 H [= 1282/83], preserved in the Türk ve İslâm Eserleri Müzesi (Museum of Turkish and Islamic Archaeology), Istanbul,[91] and

#107 A curious (and somewhat absurd) astrolabic plate by Ḥasan ibn ʿAlī dated 681 H [= 1282/83] and preserved in the Museum of the History of Science at Oxford.[92] The maker can hardly be the celebrated contemporaneous Cairo astronomer Abū ʿAlī Ḥasan ibn ʿAlī al-Marrākushī (**II-2.7** and **6.7**).[93]

In the lower left quadrant of the back of the former, there is a table labelled:

عمل هذا الجدول المبارك | لإخراج درجة الشمس | مركب على شهور القبط

"Use of this blessed table for finding the degree of the sun
arranged according to the months of the Copts."

The table, which I shall label **A**, contains information of the form:

lām sīn S n M

where *lām sīn* is an abbreviation for *tanzilu 'l-shams*, S is the last letter of the name of a zodiacal sign, n is a Coptic numeral, and M is the last letter of the name of a Coptic month. The combination means that the sun enters sign S on day n of Coptic month M. Beneath the table,

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[90] Ifrah, *Histoire des chiffres*, II, pp. 274-275 (dropped from the English version). The Coptic alphanumerical notation, on the other hand, is sensible: see *ibid*., I, p. 541.

[91] See Nasr, *Islamic Science*, p. 120 (plate 73) (with a caption on p. 243: "Seljuk astrolabe of the 6th/12th century" (!)); and King, *Mecca-Centred World-Maps*, pp. 76-78 and 600-602, on the gazetteer and the many associated problems.

[92] Gunther, *Astrolabes*, I, pp. 239-240 (no. 107); and Mayer, *Islamic Astrolabists*, p. 48.

[93] This assertion is made in my EI_2 article "al-Marrākushī". François Charette is (rightly) of the opinion that this article did not give enough credit to al-Marrākushī for all of the original material that is in his book. See his forthcoming article al-Marrākushī in *BEA*.

Fig. 3.2e: The table on the back of the astrolabe of Ḥasan ibn ʿUmar al-Naqqāsh (#4036). Note the entries in ṣilver inlay. [Courtesy of the Türk ve İslâm Eserleri Müzesi, Istanbul.]

Fig. 3.2f: The tables on the back of an astrolabic plate by Ḥasan ibn ʿAlī (#107). [Courtesy of the Museum of the History of Science, Oxford.]

upside down, is the word *nasī*ʾ, referring to the epagomenal days after month *yā*ʾ = Misrā.

On the back of the latter instrument, illustrated by Gunther, there are two tables of the kind. In the one on the left (which I label **B**) the abbreviations *lām sīn* are used, in the one on the right (**C**) the words *tanzilu 'l-shams*) are written out in full. In both the names of the zodiacal signs are written in full. In **B**, abbreviations are used for the names of the Coptic months, and in **C**, the names are written out. Both tables begin with Virgo so that the epagomenal days are mentioned in the first line rather than the last as in **A**. The information in both tables is identical but differs slightly from that in **A**.

The information in these three tables **A**, **B** and **C** is summarized in the following table, in which the Roman numerals relate to the Coptic months starting with Tūt. The last column, labelled **R** for recomputation, shows the actual days when the sun enters the signs reckoned from a contemporaneous Egyptian table of the solar longitude as a function of the date in the Coptic calendar, found in the treatise of Abū ʿAlī al-Marrākushī.[94] Where two days are given, the transfer occurs close to midnight and the one underlined is the "actual" day, found by interpolation, an operation that would have been beyond our astrolabists.

Sign	Month	Day		
		A	**B/C**	**R**
Libra	*Tūt*	19	18	19
Scorpio	II	19	18	19
Sagittarius	III	19	18	19
Capricorn	IV	18	18	18/19

[94] Sédillot-père, *Traité*, I, pp. 136-137.

Aquarius	V	18	18	18
Pisces	VI	17	18	18
Aries	VII	17	18	18
Taurus	VIII	18	19	19
Gemini	IX	20	20	20
Cancer	X	21	21	21
Leo	XI	22	22	22/23
Virgo	*Misrā*	23	23[a]	23/24
	epag. days	-	?[a]	

[a] In **B** there is an associated symbol that I cannot interpret.

In brief, then, the remains of the table on the back of the Cairo mater are in the tradition of the kind of table represented by **A-C**.[95] I find it curious that this kind of table does not seem to be found in Coptic or Ethiopic calendrical compilations.[96] More serious astronomers would have engraved (and did engrave) annular scales showing the correspondance between the solar longitude and the solar months.

4 An undated astrolabe mater by Muḥammad ibn Shaddād (al-Baladī) (with a replacement Maghribi rete)

International Instrument Checklist #1179.
Present location unknown, presumed destroyed. In 1864 this piece was in the possession of the orientalist Dr. Johann Gottfried Wetzstein of Berlin, who during 1848-62 had been *Konsul* in Damascus.[97] (I have consulted the Deutsche Staatsbibliothek in Berlin (formerly Berlin-West) and the Universitätsbibliothek in Tübingen on the Nachlaß Wetzstein, in both cases to no avail.)
Brass. Dimensions unknown.
Bibliography: Dorn, "Drei arabische Instrumente", pp. 115-118, with an illustration of the back on p. 116.

The maker is known to us as a disciple of Nasṭūlus. Ibn al-Nadīm lists him as Muḥammad ibn Shaddād *al-Baladī*, that is, from al-Balad, a town on the Tigris near Mosul. Because of the orthography of the star-names (one dot below the line for *fā'* and one above for *qāf*), Dorn thought that this was a Maghribi piece. However, he did note that *sīn* was used for 60 on the

[95] For a sets of dates for the entry of the sun in the signs in the *Syrian* calendar see King, "Early Islamic Lunar Crescent Visibility Tables", pp. 218-219.

[96] Neugebauer, *Abu Shaker's Chronography*, and *idem*, *Ethiopic Astronomy and Computus*. It should be remembered that the most (or only?) significant medieval work on mathematical astronomy written by a Copt—the astronomical tables of Ibn al-ʿAssāl—has never been studied. See *Cairo ENL Survey*, no. C10.

[97] See further Fück, *Arabische Studien in Europa*, p. 191.

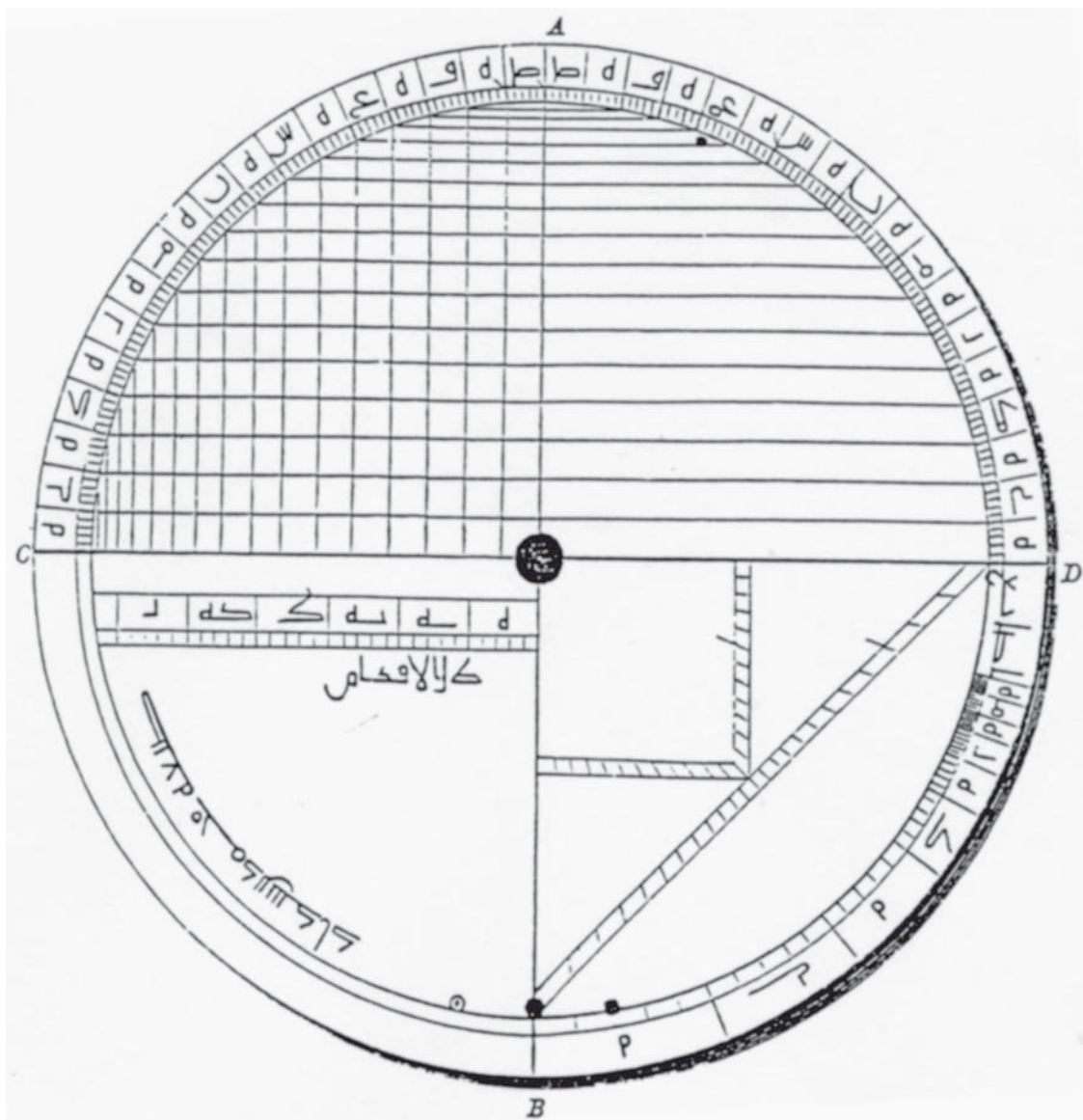



Fig. 4: The back of the lost astrolabe of Muḥammad ibn Shaddād (al-Baladī) (#1179). [From Dorn, "Drei arabische Instrumente", p. 116

scales as opposed to *ṣād*. In fact, only the rete is of Maghribi provenance, and it was clearly a replacement—see below and also §1.6.23b of the Frankfurt catalogue.

No information is available on the size or the shape of the throne. The scale on the rim was divided 5°/1°-5° (without hundreds).

The rete—see below—was soldered onto a single plate for latitude 11°, stated to be for Aden, but the value of maximum daylight promised there is obscured by the rete (*ʿarḍ ʿadan y*ʾ

sāʿātuhu —). On the other side were markings for latitude 21° corresponding to Mecca with maximum daylight 13;19^h. This value corresponds only to obliquity 24° and is in error by +1′ for obliquity 23;51°. Dorn gave no information on the altitude circles, and presumably there were no markings on the mater.

The back bears two altitude scales divided 5°/1°-5°. The upper left quadrant displays horizontal and vertical parallels for each 5° up to 80°, and the upper right one only corresponding horizontals. In the lower right quadrant there is a shadow square bounded by a diagonal shadow-scale (unusual), both serving base 12. The scales on both are divided for each digit and are unlabelled. There is additional scale on the rim for horizontal shadows to base 12 divided 5/1-5 up to 50 digits. In the lower left quadrant there is a uniform horizontal scale for measuring horizontal shadows to base 7, parallel to the horizontal axis and marked *ẓill al-aqdām*. The lower side of this scale, on which the shadow is to be measured, is 7 units below the axis, where the length of the graduated scale is 30 units. This was clearly intended to be used in conjunction with the altitude scale in the upper right quadrant; an alidade would show, for example, that the shadow corresponding to altitude 45° was 7 feet. This feature was introduced by al-Khwārizmī and is otherwise attested only on a late ʿIrāqī astrolabe (#4131—see **Fig. XIIa-B3**, and also §2.1.1 of the Frankfurt catalogue). Inside the rim of the lower left quadrant is the inscription in *kūfī* script:

صنعه محمد بن شدّاد

"Constructed by Muḥammad ibn Shaddād."

Replacement parts

Alas Dorn did not illustrate the rete, but he did state that the star-names were written in a Maghribī script, and that it bore pointers for 22 stars recorded by him as follows (not ordered). We now know that these are, appropriately, in the *Western* Islamic tradition:

al-kaff al-jadhmāʾ
al-dabarān
rijl al-jawzāʾ
al-ʿayyūq
mankib al-jawzāʾ

---

al-ʿabūr
al-ghumayṣāʾ
wasaṭ al-shujāʿ
ʿunuq al-shujāʿ
qalb al-asad

---

al-aʿzal
al-rāmiḥ
al-fakka
qalb al-ʿaqrab
al-ḥawwāʾ

---

al-wāqiʿ
al-ṭāʾir
dhanab al-dajāja
al-qiṭʿa rare—probably *qiṭʿat al-faras*
dhanab al-jady
mankib al-faras
dhanab qayṭūs

Perhaps it relates to *qiṭʿat al-faras*, α Equulei (on which see Kunitzsch, *Arabische Sternnamen in Europa*, pp. 170-171, no. 114).

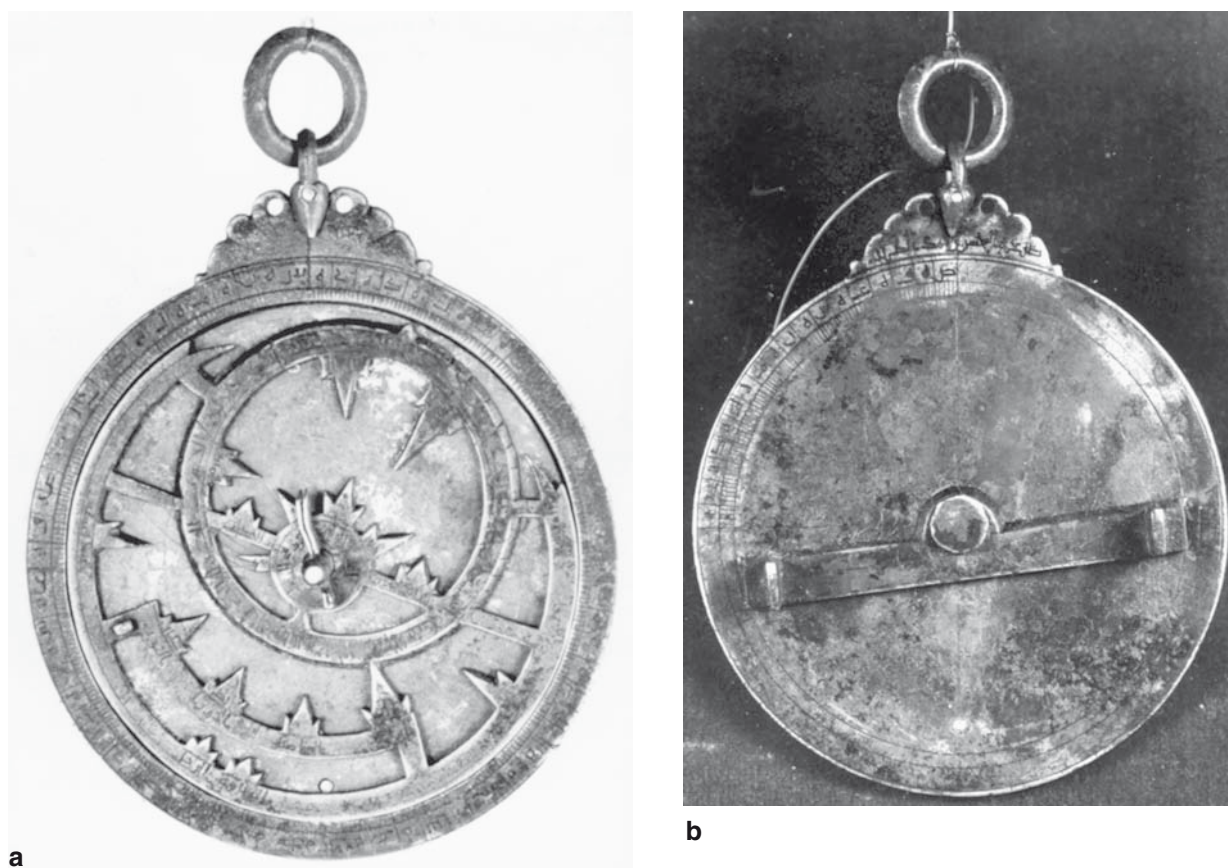
5 An undated astrolabe by al-Muḥsin ibn Muḥammad al-Ṭabīb (perhaps made in Rayy)

International Instrument Checklist #4180 = #3522 = #3527 = #3904 = #3919. [I suggest that all IIC numbers except the new one #4180 be dropped henceforth.]
Formerly Rockford, Illinois, Time Museum, inv. no. 507. Originally acquired from "an old excavation site near Rayy" and then in the collection of K. F. S. D. Gilkes, Sussex (#3904). Later apparently in the Landau Collection, Paris (#3522 and #3527). Auctioned at Sotheby's of London on 19.12.1966 (lot 71) and purchased by the Time Museum (#3919). Auctioned at Sotheby's of New York in October, 2004; present location unknown.
Brass. Diameter: 89 mm.
Bibliography: Price *et al.*, *Astrolabe Checklist*, has four separate entries, in none of which the name is given correctly. See *London Sotheby's 19.12.1966 Catalogue*, lot 71 (not seen); Anthony J. Turner in *Rockford TM Catalogue*, pp. 60-63 (no. 1) with colour illustrations of the front, back and plate. The star *al-qiṭʿa*, if that was the correct reading, is not attested on any other early astrolabes. (I cannot speak for late ones, but this rete is probably late anyway.) On the star-positions see Stautz, *Mathematisch-astronomische Darstellungen auf mittelalterlichen Instrumenten*, pp. 46-47 and 184.

This piece is clearly of early provenance. The position of Regulus on the rete is difficult to determine accurately but it is clearly closer to the beginning of Leo than its end; this indicates a dating to the 10th century, if not earlier.

The throne has one hole and three large lobes and one small one on each side. The suspensory apparatus attached to a smaller hole at the middle is probably original. The rim is rivetted to the back. The scale on the rim is divided 5°/1°-5° (without tens and hundreds). The mater is fitted with a pin at 0.74 of the radius below the centre and is devoid of markings but for two circles corresponding to the inside and outside of the circumferential frame on the rete (see below).

The rete has a rectilinear equinioctial bar and a small ^-shaped frame below the central disc. The lower equatorial bar lies outside the equator and on the left-hand support, there is a handle. A circle corresponding to the winter solstitial circle has been engraved. A dummy pointer is symmetrically placed with respect to that for *qalb al-ʿaqrab*, and the pointer for *al-wāqiʿ* is pierced by a small hole (see **3.1**). Altogether there are 19 stars (including one unnamed one) indicated by dagger-shaped pointers, as follows:

jasad qayṭus	*janāḥ al-ghurāb*
[*al-ghūl*] name not visible	————————
ʿayn al-thawr	*al-rāmiḥ*
yad al-jawzāʾ usual order reversed	*munīr al-fakka*
al-rijl usual order reversed	*al-qalb*
al-yamāniya	*al-ḥawwāʾ*
————————	————————
al-shaʾāmiya	*al-wāqiʿ* see above
qalb al-asad	*al-ṭāʾir*

Figs. 5a-b: The front and back of the astrolabe by al-Muḥsin ibn Muḥammad al-Ṭabīb (#4180). [Photos from the archives of Alain Brieux, courtesy of Dominique Brieux. See also the different illustrations in *Rockford TM Catalogue*, pp. 60-63.]

[*dhanab al-jady*]	unnamed, position correct	*al-mankib*
al-ridf		*al-khaḍīb*

The positions are not particularly accurate (with the exception of [*dhanab al-jady*]!), but no systematic error is apparent (Stautz).

A single plate, presumably originally one of several, bears two sets of altitude circles for each 6° of altitude, one for latitude 31° with maximum length of daylight 14;3^h, which is correct only for obliquity 23;51°. The other serves latitude 24° (not 34° as recorded by Turner), serving Medina, but the value of maximum daylight is illegible. The hole is slightly off the meridian. The fact that the other plates are missing makes it difficult to speculate about the provenance, although Rayy is most likely.

On the back an inscription along the bottom of the throne reads:

صنعه المحسن بن محمد الطبيب

"Constructed by al-Muḥsin ibn Muḥammad al-Ṭabīb,"
the epithet indicating that our astrolabist was also a medic. The back is divided into four quadrants, and there are two circles around the rim. Only in the upper left quadrant have these been used, namely for an altitude scale divided 5°/1°-5°.

The alidade is rectilinear and bears no markings. The ends are almost rectangular but for a small protrusion to indicate the fiducial edge. The sights have one hole each. The alidade appears to be original. (A. J. Turner considered that it was unusable and hence a replacement.)

6 An unsigned undated Abbasid astrolabe with later additions by a European (the so-called "Astrolabe of Pope Sylvester II")

International Instrument Checklist #101 = #9001.
Florence, Museo di Storia della Scienza: 1113. Formerly in the Tribuna Galileo in Florence. Provenance? An electrotype is preserved in the Museo Naval de Madrid (inv. no. ?). Exhibited at Santa Cruz in 1985 (electrotype) and at Linz in 1990-91 (original) and at Granada in 1992 (original?).
Brass, with a leather case that has nothing to do with the original instrument. Diameter: 162 mm.
Bibliography: Saavedra, "Astrolabe arabe", *passim* (where the instrument is dated to *ca*. 1000 but the association with the Pope is accepted: "L'astrolabe a donc été fait en Orient, et probablement au Caire (lat. 30°), pour le Pape Sylvestre, à la fin du X[e] siècle."), and *idem*, "Astrolabios árabes en el MAN," pp. 411-413; Gunther, *Astrolabes*, I, pp. 230-232 (no. 101: "The Astrolabe of Pope Sylvester II") with illustrations of the front and back in Pl. LII; *Florence 1954 Catalogue*, pp. 64-65 (no. 1113); García Franco, *Astrolabios en España*, pp. 131-160 (no. 3) for a detailed description (with illustrations of the front, back, plate for 36° and rete); Destombes, "Astrolabe carolingien", p. 14; *Florence 1987-88 Catalogue*, pp. 14 (no. 1.2: "la tradizione lo fa risalire a Carlo Magno"); *Santa Cruz 1985 Exhibition Catalogue*, pp. 78-79 ("conocido con el nombre de "Astrolabio de Alfonso el Sabio" [*sic*]") (with colour illustrations of the front and back); *Linz 1990 Catalogue*, II, pp. 20-22 (no. 17) (with a fine colour illustration of the front). The description by García Franco and the one by Vernet *et al*. in the Santa Cruz Catalogue are based on the electrotype preserved in the Museo Naval, Madrid. It is cute that this ʿIrāqī astrolabe alone features on the poster of the exhibition "Al-Andalus y la Ciencia" held in Granada in 2004. On the star-positions see Stautz, *Mathematisch-astronomische Darstellungen auf mittelalterlichen Instrumenten*, pp. 48-49 (no details).

This instrument has in all probability nothing to do with Pope Sylvester II, otherwise known as Gerbert of Aurillac. It is clearly Eastern Islamic, not Western Islamic, and dates from the 10[th] century. García Franco dated it to 1002. The *kūfī* script is distinctive: note the "crossed swords" used for the *lām-alif* ligature. The accompanying leather box bears an inscription in Latin that can hardly relate to this instrument, and the mater bears a Latin inscription in a different hand. (Both have been studied by García Franco.) There is clear evidence on the instrument of the handiwork of a modern (early-19[th]-century ?) faker.

The throne is slightly raised on a long base and the central part is low and has one hole and three lobes (the innermost one rather squashed) on each side. The suspensory apparatus, a simple shackle and a ring attached to a smaller hole at the middle, is probably original. The mater bears a scale divided 5°/1°-5° (without hundreds). But for a peg at the bottom and a crudely-written Latin inscription—see below—it is devoid of astronomical markings.

The rete has a rectilinear equinoctial axis and a small trapezoidal frame between the central disc and the middle of the northern ecliptic. The lower equatorial bar, which is concentric with the equator but has a slightly larger radius bears a handle on the left-hand support. The scale of the ecliptic is divided for each 2° but not labelled. The name *al-samaka* is used for Pisces. There are dagger-shaped pointers for 25 stars, as follows:

baṭn qayṭus
al-ghūl
ʿayn al-thawr
al-ʿayyūq
rijl al-jawzāʾ
yad al-jawzāʾ

---

al-shiʿrā al-yamāniya
al-shiʿrā al-shaʾāmiya
ʿunuq al-shujāʿ
rukbat al-dubb
qalb al-asad
janāḥ al-ghurāb

---

al-aʿzal

al-rāmiḥ
al-fakka
ʿayn [*sic*] *al-ḥayya*
qalb al-ʿaqrab
al-ḥawwāʾ

---

al-wāqiʿ small hole

---

al-ṭāʾir
al-ridf
dhanab al-jady
al-mankib
dhanab qayṭus
al-khaḍīb

The position of Regulus is Leo 15° which corresponds to the early 10th century. In general the star-positions are fairly accurate but not as accurate as those on the Kuwait astrolabe of Nasṭūlus (**3.1**).

The two plates have altitude circles for each 6° (but *no* azimuth circles) and serve the following latitudes:

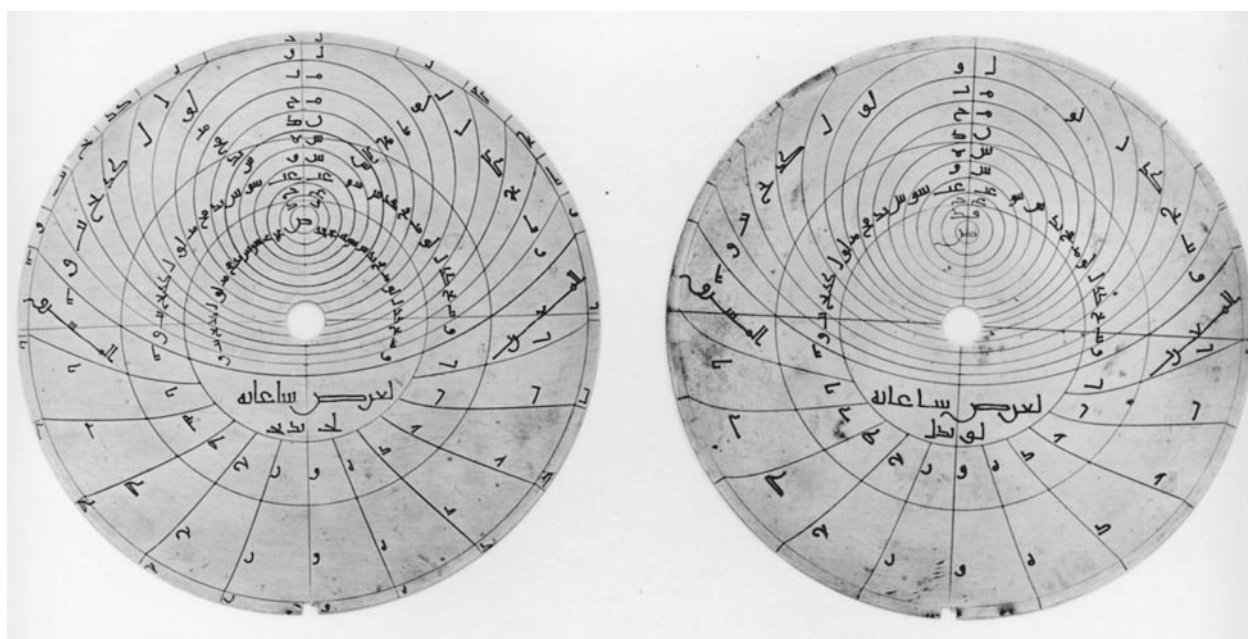
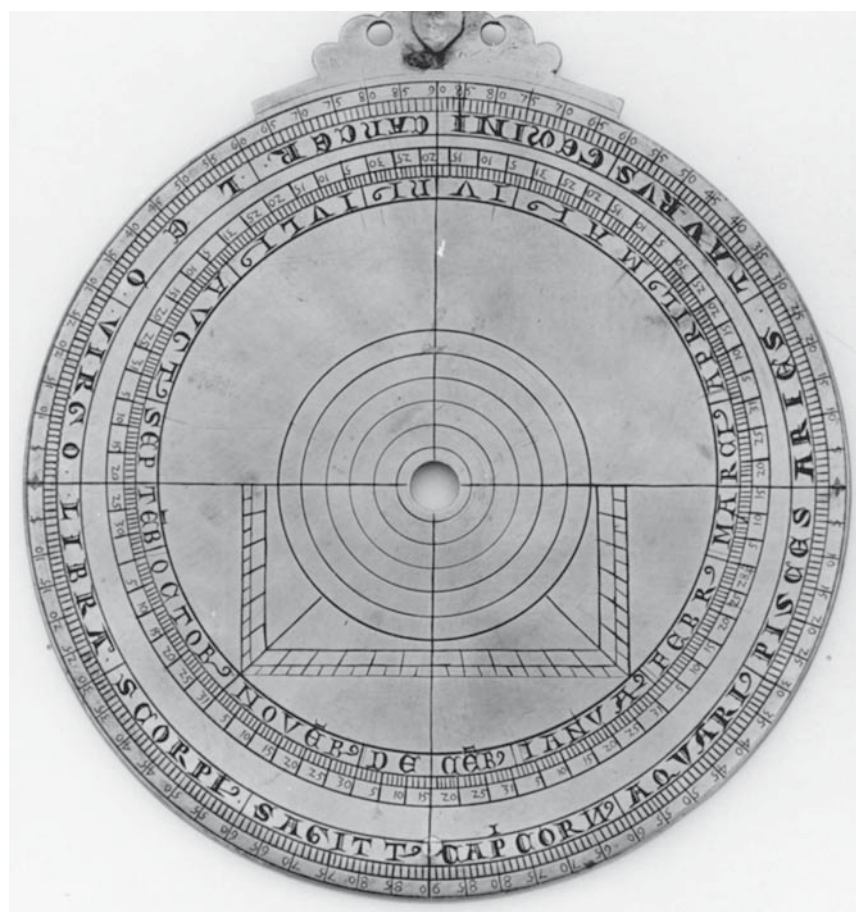
30°	14^h	[+2]
33	14;13	[0]
36	14;30	[0]
42	15	[-8]

The altitude arguments are labelled three times up to the zenith and the seasonal hours are labelled twice. The lengths of daylight are recomputed for obliquity 23;51°. It is probable that the maker worked in Baghdad, this being the only location represented by a latitude which does not correspond to one of the climates. Also, the only plate which is marked around its outer rim with the arguments for the altitude circles and the numbers of the hours is that for

a

Figs. 6a-c: The front and back of the unsigned undated Abbasid astrolabe in Florence (#101), together with the plates for latitudes 33° and 36°. The additional markings on the back by a European are highly dubious and merit further examination. [Courtesy of the Museo di Storia della Scienza, Florence.]

b

ARIES
PISCES
AQVARI
CAPCORN
SAGITT
SCORPI
LIBRA
VIRGO
TAVRVS
GEMINI
CANCER

c

latitude 33°. (Saavedra did not know that 33° was a commonly accepted Abbasid value for Baghdad, and assumed that the instrument must have been made in Cairo, to which 30° corresponds nicely.)

The alidade is probably not original—see below.

Later markings and paraphernalia

The markings on the back are in a European hand but clearly after an Andalusī model. The letters are distinctly medieval but the numbers are deliberately late Renaissance. There is also an unmarked set of concentric circles on the back; clearly the person who reworked this instrument did not trust himself to fill in the calendrical information (compare **Figs. XIIIa-10.1b** and **10.2a**). The layout of the circles is virtually identical to that of the Madrid and Oxford astrolabes of Ibrāhīm ibn Saʿīd al-Sahlī (see **Fig. XIIIa-10.2b**). The differences in the details of the markings on the Florence instrument are as follows:

(1) there is no separate scale for the degrees of each zodiacal sign (one has to use the divisions of the altitude scale, which run in the wrong direction);
(2) there is a double shadow square rather than a single one;
(3) the equinox is at March 15 rather than 14 as on the Oxford instrument (although the Madrid one also has 15);
(4) the calendrical scale is a mess: the divisions of the months do not correspond to the days (note, for example, the 5-unit division corresponding to the last $3^1/_4$ (= $28^1/_4$ - 5×5) days of February).

Note the use of the fraction $^1/_4$ (see further **XV-5**). The names of the signs and months are written:

ARIES—TAVRUS—GEMINI—CANCER—LEO—VIRGO
*LIBRA—SCORPI9—SAGITT9—CAP*CORN̲9—AQVARI9—PISCES*

IANVA9—FEBR9—MARCI9—APRIL9—MAI9—IVNI9—IVLI9
AVGT9—SEPTĒB—OCTOB9—NOVĒB9—DECĒB9

In these partially abbreviated forms we note the standard kinds of abbreviations in medieval Latin, including the suffix -9 (on which see **XV-3.2**), the line over an E to indicate that the following letter M is suppressed, and a small I over a P (here indicated by P*) to show that several letters have been omitted. The N in CAP*CORN9 is reversed. All these features could be taken as supporting a genuine medieval engraver, but until the piece has been examined with a microscope I shall remain unconvinced.

In view of the problems associated with these markings I suspect that the back was reworked by an instrument faker. Saavedra claimed that the instrument had been made for the French Pope Sylvester II towards the end of the 10th century, an association of which already Gunther was rightly suspicious.

The alidade is counter-changed at the middle and the folding vanes each have two star-shaped holes. Both it and the declination rule are probably not original. Neither bears any markings. The ensemble is held together by a paper-clip.

Inside the mater is a lengthy Latin inscription mentioning the date 1490. García Franco has attempted to decipher it (p. 147, fig. 44), but without complete success ("no puede traducirse un conjunto útil y fructífero"), and I have not studied it.

The inscription in ink on the leather cover (16th century ??), which is in a different hand, reads (after García Franco):

Astrolabium arabicum ex Hispania delatum et paratum eo tempore quo aequinoctium vernum haerebat in die 15 martii, id est, anno Christi 1252 quo Alfonsus Rex Hispaniarum [*sic*?] *restituit motus coelestes.*

The equinox at March 15 corresponds to the 10th century rather than the 13th so that this inscription is nonsense. As Saavedra correctly observed: "il n'y a rien d'exact ni de vraisemblable dans cette note". The instrument has been described as "concocido con el nombre de "Astrolabio de Alfonso el Sabio"" (Vernet *et al.*), which appellation is also to be supressed.

7 An unsigned mater and plates

International Instrument Checklist #4022.
London, Science Museum: inv. no. 1981-1380. Purchased from Dr. Ing. Paolo Girardi of Beirut for the Collection of Leonard Linton of Long Island. Auctioned by A. Brieux of Paris in 1980.
Brass. Diameter: 117 mm.
Bibliography: *Linton Collection Catalogue*, p. 83, no. 160 (with a colour illustration of the back on the facing page): "Syria ... 10th century".

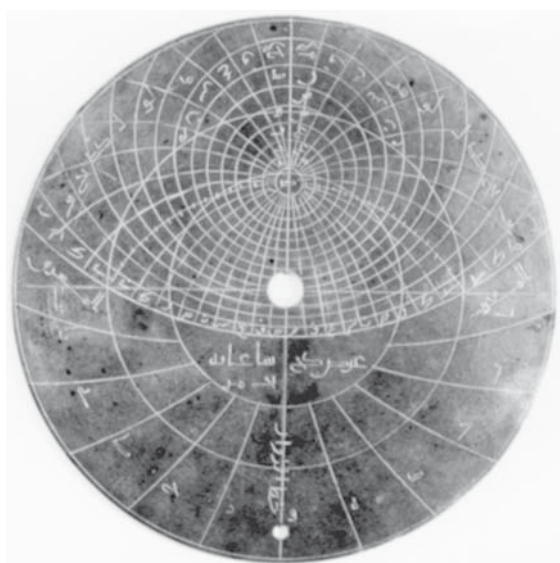
The throne is raised and has one hole and two lobes on each side. The suspensory apparatus, a simple shackle and circular ring attached to a smaller hole at the middle, appears to be original. The scale on the rim is divided 5°/1°-5° (without tens or hundreds). There is a peg to hold the plates at 0.76 of the radius below the centre of the mater, which bears a set for a specific latitude—see below.

The rete is not original, being clearly Ottoman and probably of Egyptian or Turkish provenance—see §2.2.6a of the Frankfurt catalogue.

The two plates out of an original three, together with the mater, bear altitude circles for each 6° and serve latitudes:

M	24°	13;30^h	[-1]
1a	28	13;47	[-2]
1b	31	14; 4	[+1]
2a	36	14;30	[0]
2b	39	14;48	[0]

The altitude arguments are in *kūfī*, as are the words *al-mashriq* and *al-maghrib* below the extremities of the horizon (on all but 2a). It is probable that the original third plate served latitude 33° (see below). The lengths of daylight are computed for obliquity 23;51°. A third plate, now missing, probably served latitude [33° (Baghdad)] (see below).

The back bears two altitude scales divided 5°/1°-5° and a double trigonometric grid in the upper quadrants with horizontal and vertical parallels for each 5° up to 80° and two concentric

Figs. 7a-d: The front and back of an unsigned Abbasid mater (#4022) and the plate for latitude 28°, together with the spurious rete. (The photos of the other plates are too dark to reproduce.) [Courtesy of The Science Museum, London.]

semicircles with radii 24 and 28 units (where the radius of the grid is 60 units). The first of these, which became standard on later trigonometric grids, serves to find the solar declination from its longitude. The second semicircle, not attested on any other known instrument, serves to find the equation of half-daylight (see **I-7**, *etc*) for any solar longitude, specifically for latitude 33°, that is, [Baghdad]. On the rim of the empty lower left quadrant, there is a scale of shadows to base 12 divided 5/1-5 up to 45 and then 5/5 up to 85 (labelled up to 50). In the lower right quadrant there is a universal horary quadrant, but the scale divided 5/1-5 on the rim (from [0°] on the right to 45° at the bottom) is not related to this. In fact, if one sets one end of an alidade at the meridian on the scale in the upper left quadrant the other end will mark the altitude at the beginning of the afternoon prayer on the scale in the lower right. This feature is not attested on any other known instrument from the early period.

There is no alidade, but there is a pin (now attached to the throne with a thread). The ensemble is now held together with a modern nut and bolt.

Later additions and replacements

On the late replacement rete, probably made in Egypt, see §2.2.6a of the Frankfurt catalogue.

The azimuth circles for each 10° of argument on the two plates described above appear to be later additions, doubtless by the maker of the rete; certainly they are less carefully drawn than the original markings. The azimuth arguments, the name *al-Madīna* on M, the expression *khaṭṭ al-zawāl* on each of the plates, as well as the words *al-mashriq* and *al-maghrib* on 2a, are in the same untidy *naskhī* hand. They were engraved by the same person who prepared the third plate for:

3a	30°	Cairo	13;58^h	[0]
3b	42	Edirne	15; 7	[-1]

Here there are altitude circles for each 6° and azimuth circles for each 5° and 10°, respectively. This third plate has two holes on the meridian, and the markings on each side are upsidedown with respect to each other. The values for longest daylight on this replacement plate were computed for obliquity 23;51°.

8 Two instruments by Ḥāmid ibn ʿAlī (al-Wāsiṭī)

Ibn Yūnus (**0d**) mentions Ḥāmid ibn ʿAlī al-Wāsiṭī in the same glowing terms as Khafīf (**1**). He also had an astrolabe by Ḥāmid in his possession and used it to enlighten some colleagues (see the comments on the latitude of Cairo in **2**). But al-Wāsiṭī is also known as an astronomer of merit.[98] Parts of two astrolabes by him have survived and they attest to his competence and initiative. The first—the more technically interesting piece—is dated 343 H [= 954/55]; the most important part of the date on the second—namely, the tens—is no longer legible. Both of these pieces had an association with Egypt, and perhaps one of them is the astrolabe of Ḥāmid's that Ibn Yūnus himself used.

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[98] On Ḥāmid see also Mayer, *Islamic Astrolabists*, p. 45, and supp., p. 295; Suter, *MAA*, p. 40 (no. 76); and Sezgin, *GAS*, VI, p. 207.

8.1 A mater of a "complete" astrolabe dated 343 H

International Instrument Checklist #100.
Present location unknown. Palermo, Museo Nazionale: inv. no. 2131—liberated from the Museum about 50 years ago. Earlier provenance?
Brass. Diameter: 154 mm (from Caldo).
Bibliography: Mortillaro, "Astrolabio arabo del nono secolo", especially the lithograph plates (front and back); Caldo, "Astrolabi di Palermo", esp. pp. 6-9, and figs. 1 and 2 (*ditto*); Gunther, *Astrolabes*, I, p. 230 (no. 100): "(this mater) has been stated by that competent authority, Almerico da Schio, to be merely a twelfth-or thirteenth-century copy of an early original" (!!); Destombes, "Astrolabe carolingien", pp. 13-14.

Fortunately this piece was illustrated by V. Mortillaro in the mid 19th century. His description is marred by misreadings of all but the simplest of numbers on the instrument, including the date of construction and the latitudes served by the markings, and by some absurd astronomical and geographical conclusions, such as that some of the markings were intended specifically for Palermo. These conclusions were questioned already by L. Caldo.

The throne has four lobes of different size and a large hole on either side of the middle. The shackle has a shovel-shaped base on each side and carries a circular ring. The scale on the rim is divided 5°/1°-5° (without hundreds).

The mater bears four sets of full horizons for latitudes:

20°	30°	40°
21°	31°	41°
22°	32°	42°
23°	33°	43°

This leads me to suspect that there might originally have been similar sets of markings on other plates for latitudes between 24° and 49°, although it is not obvious how they would have been distributed. This is *the earliest surviving plate of horizons*, although it had been introduced almost a century earlier by Ḥabash al-Ḥāsib.[99] On each of the base diameters is engraved the expression *ufuq al-istiwāʾ*, "the horizon of the equator". Around the third of five concentric circles (see below) are written (not in order) four of these latitudes with the corresponding lengths of maximum daylight (*ʿarḍ* — *sāʿātuhu* —):

40°	14;54^h	[0]
41	15; 1	[0]
42	15; 7	[-1]
43	15;15	[0]

(This particular circle appears to have no astronomical significance—see below.) The values for daylight correspond only to obliquity 23;51°.

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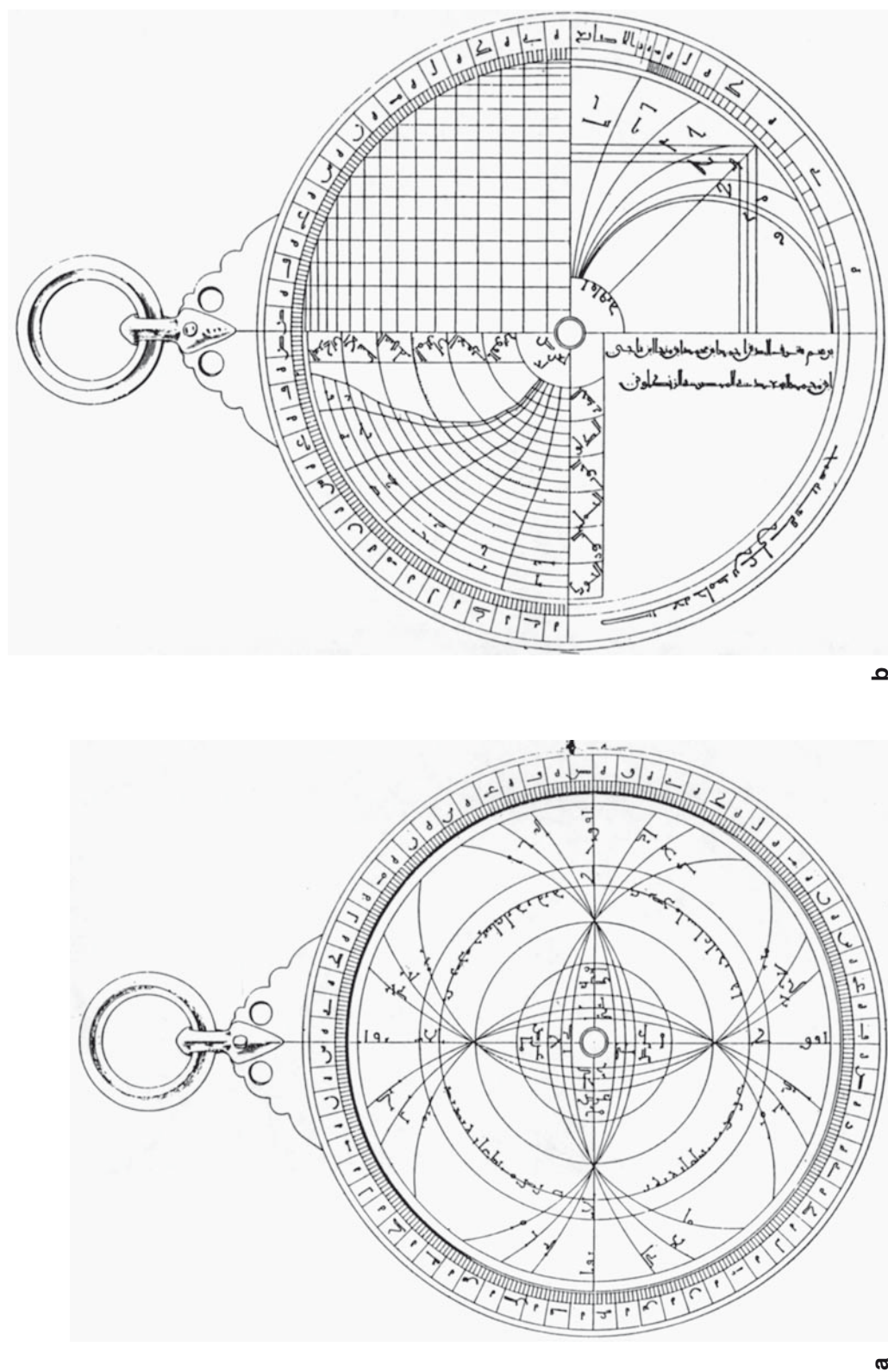
[99] For the evidence see Morley, *Astrolabe of Shāh Ḥusayn*, p. 7, n. 12, and read "Ḥabash" for "Ḥanash". A text by Ḥabash has not been identified.

Figs. 8.1a-b: The front and back of the lost Palermo mater of Ḥāmid ibn ʿAlī al-Wāsiṭī (#100). [From Mortillaro, “Astrolabio arabo del nono secolo”.]

The first, second and fourth circles one would expect to correspond to the tropic of Cancer, the celestial equator and the tropic of Capricorn, and the fifth to some southern declination. As we shall show, this is not the case. Now the equatorial circle is improperly drawn since the horizons intersect just outside it. Its radius on the copy that I have used of the lithograph published by Mortillaro is 3.2 cm, but the distance from the centre to these four points of intersection is 3.3 cm. If one assumes a stereographic projection and an equatorial radius of 3.2/3.3 cm, the radii correspond to declinations of approximately:

$23^1/_2°/25°$ 0°/0° $-15^1/_2°/-13^1/_2°$ $-21^1/_2°/-19^1/_2°$ -36°/-36°

respectively. The first and fourth circle are clearly for the solstices, the second being, of course, for the equinoxes. It is evident that the third circle has no astronomical significance, merely serving the inscriptions engraved on it (see below). The value -36° is to some extent arbitrary. We are dealing with an astrolabe with extended radius of projection, such as were sometimes called *kāmil*, "complete", in medieval scientific Arabic.[100] A solitary plate for such an instrument possibly from the 10th century survives: see **12.1**; here the outer circle also corresponds to *ca*. -36°.[101] A solitary rete and plate for such an instrument by Muḥammad ibn Abī Bakr al-Rāshidī of Isfahan *ca*. 1225 survives (#4031).[102] Clearly, it would be worth taking apart the Cairo instrument of Ḥāmid ibn ʿAlī (**8.2**) to see whether there were such interesting markings on *its* mater.

The back bears two altitude scales divided 5°/1°-5° in the two upper quadrants. In the left of these is a graphical representation of the solar altitude at the six seasonal hours (the spaces are labelled 1/12—2/11—...—6/7) with two radial ecliptic scales spanning about four-fifths of each axis. There are quarter-circles for each 10° of each sign, the names Capricorn to Gemini (with *al-ḥūt* for Aquarius) appearing on the horizontal radius and Cancer to Sagittarius on the vertical one. The horary quadrant is stated to be for latitude 33° (*li-ʿarḍ lj*), that is, [Baghdad]. Since the maximum solar altitude is clearly 81°, the obliquity used was probably 24° or 23;51°. In the upper right quadrant there are two sets of horizontal and vertical parallels for each 5° of arc on the scale up to 80°.

On the lower right is a universal horary quadrant labelled (*sāʿāt) āfāqiyya*, "(seasonal hours) for all latitudes". The spaces are labelled 1/12—2/11—... 6/7. These markings were to be used in conjunction with the scale on the opposite quadrant to find the solar altitude at the seasonal hours. The frame of a shadow square covers the markings for the hours, but there are no divisions along its sides. It is significant that the universal horary quadrant is superposed on what could have been used as a shadow square—see **XIIa-B**. On the lower right rim there is a scale for the horizontal shadows to base 12 (*al-aṣābiʿ*) divided 5/1-5 up to 40 and 5-5 on to 50. An inscription in *kūfī* in the lower left rim reads:

صنعه حامد بن علي في سنة شمج

[100] See Charette, *Mamluk Instrumentation*, pp. 63-65.

[101] *Ibid*., p. 64.

[102] #4031— London, Nasser D. Khalili Collection, inv. no. SC11—see *London Khalili Collection Catalogue*, I, pp. 210-211 (no. 122), and Charette's comments (*op. cit*., p. 64-65), notably the fact that the outer limit for the declination is *ca*. -35°.

"Constructed by (*ṣanaʿahu*) Ḥāmid ibn ʿAlī in the year 343 (Hijra) [= 954/55],"
and another, also in *kūfī*, to the left of the vertical radius in the lower left quadrant reads:

برسم شرف الدين أحمد ابن محمد ابن منجا ابن ناجي ابن محمد السعدي المصري الزنكلوني

"By order of Sharaf al-Dīn Aḥmad ibn Muḥammad ibn Munajjā ibn Nājī ibn Muḥammad al-Saʿdī al-Miṣrī al-Zankalūnī."

This latter is unknown to me, but he was cleary a man of some consequence. He was an Egyptian (*Miṣrī*), but he was not necessarily in Egypt when this dedication was engraved. As we have seen, the horary quadrant was prepared for Baghdad. Zankalūn, a popular rendering of Sankalūm, is a village in Egypt near Zagazig.[103] The fact that he is called *al-Miṣrī al-Zankalūnī* probably indicates that he added the appelation al-Miṣrī when people in Baghdad asked him where on earth Zankalūn was, and he answered that he actually came from Sankalūm, which is near Zaqāzīq. (Arabic speakers also find these names a bit weird.) The name al-Saʿdī is less informative, probably indicating an ancestor named Saʿd. The inscription appears to be contemporary with the instrument, and names (*laqab*s) of the kind Sharaf al-Dīn are attested by the 10th century.[104] Note the incorrect orthography of *ibn;* the word should be written without the *alif* unless it occurs at the beginning of a new line of text, and here all occurences are with *alif*.

8.2 A mater with an illegible date [3]?4 H (with a replacement rete and plates by [Muḥammad Ṣaffār])

International Instrument Checklist #3713.
Cairo, Museum of Islamic Art (Dār al-Āthār al-Islāmiyya): 15352. (There are two stickers with the number 42 on the back.) Formerly in the Harari Collection (no. 148). Earlier provenance? Exhibited at the Science Museum, London, in 1976.
Brass. Diameter: 110 mm. Thickness: 4 mm.
Bibliography: Muṣaylaḥī, *Al-Asṭurlāb*, p. 57, and pls. 7-8 (back only); *London SM 1976 Exhibition Catalogue*, pp. 100 and 102.

The later rete and various plates have been rivetted to the mater, so that unless the ensemble be dismantled there is little hope of establishing either whether the mater was originally engraved or whether there are any original plates. In 1992, I was unable to persuade the Museum administration that the rivet should be broken. My frustration was aggravated by the very unusual plate partially visible under the rete. It is strongly recommended that the absurd rivet holding this instrument unnaturally together be removed. This is an important instrument, and

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[103] al-Suyūṭī, *al-Lubāb*, pp. 128a and 142a.
[104] As pointed out in Schimmel, *Islamic Names*, p. 137 of the German version, such *laqab*s were given to vezirs and political leaders by the Abbasid caliphs in Buyid times.

it is an insult to the memory of the "Golden Age" of Abbasid science that it has been so abused in recent times.

The throne is high with one large hole and three shallow lobes on each side. The suspensory apparatus attached to a smaller hole at the middle is not original- see below. The scale on the rim is divided 5°/1°-5°, labelled from 5° to 90° clockwise in each quadrant (unusual). The back is separate from the rim and is attached by a rivet through the throne and another at the bottom of the rim. There is a peg for holding the plates at 0.77 of the radius below the centre of the mater.

Perhaps their are some original plates inside the mater. *Allāhu aʿlam*. The one that is visible under the rete is of great interest, with two sets of astrolabic markings serving two different latitudes (see below).

On the back there are altitude scales divided 5°/1°-5° on the rim of each of the upper quadrants. The upper left quadrant bears a trigonometric grid with a set of horizontal lines for each 5° of arc. The three other quadrants are devoted to astrological scales (see also **9** and **10**). For each of the zodiacal signs, which are named (Virgo is *al-sunbula*, Pisces *al-samaka*), the lengths of the limits in degrees, the symbols for their lords, and the abbreviations of the lords of day and night and the companions, are given.[105] An inscription above the right-hand horizontal axis reads: "The limits (*ḥudūd*) of the Egyptians". There is a shadow-scale to base 12 on the lower right rim divided 5/1-5 up to 35, then one division each labelled 40 then 5 (for 45). On the rim of the lower left quadrant is the inscription:

صنعه حامد بن علي لمحمد بن عبد الله ... ... (؟؟)

"Constructed by Ḥāmid ibn ʿAlī for Muḥammad ibn ʻAbdallāh (?) (in the year) [3]?4 (Hijra)."

The words underlined are barely legible, and first two numerals of the year-number are no longer visible. The translation given here dates from an inspection of the instrument in 1992. In preparing the illustrations for this publication, I found an old photo of the inscription (**Fig. 8.2c**), in which "for Muḥammad ibn ʻAbdal" is clearly legible, but is the second name really "ʿAbdallāh"? There is a ligature *x-r/z* at the end of the name, but this seems too far from the "ʿAbdal" to serve, say "ʿAbd al-ʿAzīz". I see no trace of a *dāl* (d) or any date. The former would have to look like the final *dāl* of "Ḥāmid".

Later additions

The simple head-set-type shackle with a pear-shaped frame is not original. A notched oval ring is attached to it.

The rete is clearly the work of Shams al-Dīn Muḥammad Ṣaffār, a competent Iranian astrolabist known by five other pieces dated between 878 H and 911 H [≈ 1475-1505].[106] I have compared it with one of these in the same Cairo collection (#1136). There are the

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[105] On these symbols, which were adopted by the Muslims from Byzantine sources, see Wiedemann, "Planetenzeichen auf Astrolabien", and also **XIVa-2**.

[106] See Mayer, *Islamic Astrolabists*, pp. 75-76.

a

Figs. 8.2a-b: The front and back of the Cairo mater of Ḥāmid ibn ʿAlī al-Wāsiṭī (#3713). The maker of the replacement rete can be identified. The person who ordered this to be rivetted to the mater should be rivetted somewhere. [Photo from the archives of Alain Brieux, courtesy of Dominique Brieux; other photos are in the L. A. Mayer Memorial Collection, Jerusalem.]

b

Fig. 8.2c: The problematic inscription.

distinctive pairs of claws at the top and on either side of the lower half of the rete, and there is a bird representing Vega. The scale of the ecliptic is divided for each 6° without labels. The stars represented, some with curious abbreviations of their names, are:

dhanab j(anūbī)
fam qayṭus
ghūl
dabarān
rijl
ʿayyūq (no pointer)
yad

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yamāniya
shaʾāmiya
safīna
miʿlaf
fard
qalb
mankib
dhanab s(hamālī)
khaḍīb

dubb (unclear)
sāq

---

aʿzal
ʿanāq
rāmiḥ
fakka
qalb
ḥawwāʾ

---

wāqiʿ
ṭāʾir
janāḥ
dhanab ṭ (sic: should be *al-jady)*

These stars are in the same tradition as those found on the astrolabes of Jalāl al-Kirmānī half a century earlier (see **XIVd-1-2**).

The one visible plate is also in the tradition of Muḥammad Ṣaffār. It bears astrolabic markings for two latitudes: altitude circles for each 6° for latitude [39°] on the upper half with hour curves below the horizon, and inverted altitude circles for each 6° for latitude [21°] on the lower half.

9 An astrolabe by Ḥāmid ibn al-Khiḍr al-Khujandī dated 374 H

International Instrument Checklist #111.
Formerly (?) collection of Jasim al-Homeizi, Kuwait, though apparently now in Doha, Qatar. Acquired *ca*. 1976 from Alain Brieux, who acquired from the Marquis de Gernay, who inherited it from the Contesse de Bahague. About 1930, this piece was owned by Messrs. Moradoff & Sons of London. In 1976 it was on display at the so-called "Festival of the World of Islam" at the Science Museum, London. In 1987 it was exhibited at Louisiana (in Humlebæk, Denmark).
Brass. Diameter: 151 mm. Thickness: 6 mm.
Bibliography: Gunther (*Astrolabes*, I, p. 245 (no. 111)) mentioned it briefly but had no idea who the maker was. He and Professor David S. Margoliouth, the leading Islamicist at Oxford, misread the name of the maker as Aḥmad ibn al-Khiḍr al-Najdī and the date as 778 H [= 1376], although the possibility

of 378 H (*sic*) [= 960] is discussed. Gunther noted "the vendor of the instrument had considered it far older ... but to judge from the appearance of the metal, the instrument is not of much antiquity". (Thus Gunther's innocence led to the piece not being acquired by the Oxford Museum.) L. A. Mayer (*Islamic Astrolabists*, p. 45) rightly questioned this late date, and also the maker's name. In 1962 Marcel Destombes ("Astrolabe carolingien", p. 14) correctly identified the maker. See also Anthony J. Turner and Francis Maddison in *London SM 1976 Exhibition Catalogue*, pp. 102-103 (no. 43); *Rockford TM Catalogue*, fig. 16 on p. 22 (illustrations of the front and back); *Louisiana (DK) 1987 Exhibition Catalogue*, p. 48 (no. 43), with a colour illustration of the front on p. 26; King, "Strumentazione", p. 168 (brief mention) and pp. 158, 159 and 162 (illustrations of the front, rete and two plates); *idem*, "Astronomical Instrumentation", pp. 154 and 169; *idem*, "Kuwait Astrolabes", pp. 80, 82-89 (no. 2), the first complete description; *idem*, *Mecca-Centred World-Maps*, pp. 18-19; and *idem*, *The Ciphers of the Monks*, pp. 382 and 384. On the star-positions Stautz, *Mathematisch-astronomische Darstellungen auf mittelalterlichen Instrumenten*, pp. 48-49 and 185, and on the horary quadrant *ibid*., pp. 51, 52 and 188. See now **XVII** on the quatrefoil.

The most significant and the most beautiful of all Islamic astronomical instruments from the early period of Islamic science (850-1250) is an astrolabe made by a leading astronomer of the late 10th century, al-Khujandī (d. 1000), renowned for his achievements in astronomy, instrumentation and mathematics.[107]

al-Bīrūnī wrote that al-Khujandī was unique in his abilities as a maker of astrolabes and other instruments, no mean compliment.[108] That this is true is confirmed by this sole surviving instrument of his, which is the most spectacular astrolabe of the early Islamic period.

al-Bīrūnī actually met al-Khujandī in Rayy (near modern Tehran) where the latter informed him of the enormous sextant he had constructed to measure the obliquity of the ecliptic. This sextant, with a radius of over 20 metres, was erected in the meridian plane, and al-Khujandī has left us a careful description of his observations with it and the result which he obtained for the obliquity, namely, 23;32,21°.[109] Some astronomers maintained that the obliquity was oscillating about a mean value. On the other hand, al-Khujandī clearly states that some people recognized that it was decreasing, and he is thus best known in the history of astronomy for this remark.[110] As we shall see, there is some inconsistency in his use of the obliquity on his astrolabe.

In the field of small-scale instrumentation, al-Khujandī was previously known for his invention of a device which he called "the comprehensive instrument" (*al-āla al-shāmila*) for a specific latitude. His treatise on that instrument, a hemispherical device, survives in several copies that remain to be properly studied.[111] A fine additional copy of the commentary by the

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107 On al-Khujandī consult the articles in *DSB*, VII, pp. 352-354 (by Sevim Tekeli) and *EI*$_2$, V, pp. 46-47 (by Julio Samsó), and the numerous references there cited (none of which mention his astrolabe). See also Sezgin, *GAS*, V, pp. 307-308; VI, pp. 220-227; and VII, p. 415, for manuscripts of his works.

108 See al-Bīrūnī, *Taḥdīd*, text, p. 107, and transl., p. 75.

109 See Schirmer, "Studien zur Astronomie der Araber", pp. 63-79, for a translation of the text (published by Louis Cheikho in 1908), and also al-Bīrūnī, *Taḥdīd*, text, pp. 101-109, transl., pp. 70-77, and comm., pp. 44-48, for al-Bīrūnī's summary.

110 See, for example, Sezgin, *GAS*, VI, p. 220.

111 See Sezgin, *GAS*, VI, p. 221, no. 1 (where it is erroneously stated that the instrument is an astrolabe). See Frank, "Zwei astronomische Instrumente", for details of the instrument.

12th-century astronomer and instrument-maker Hibatallāh[112]—who rendered the device universal—was stolen from the al-Homaizi Collection during 1990-91.

al-Khujandī is known to have operated in Rayy, which is where he set up his sextant. But this astrolabe was almost certainly made for use in Baghdad. That city is the only locality in the region for which 33° was accepted as the latitude.[113] This value is in fact too small by 20′, and al-Khujandī has ignored the much better results of his contemporary Ibn al-Aʿlam, namely 33;21°, and the anonymous astronomer who obtained 33;25°, a value used, for example, by the Egyptian astronomer Ibn Yūnus and his late contemporary al-Bīrūnī, neither of whom measured it themselves.

al-Khujandī's astrolabe represents the culmination of known Muslim achievements in astrolabe construction in the early period, as the astrolabe of Ibn al-Sarrāj (Aleppo, 1328/29) and the sundial of Ibn al-Shāṭir (Damascus, 1371) represent the culmination in instrumentation in the later period (see **XIVb**). al-Khujandī's astrolabe had never been published before 1995, although illustrations of it had appeared in various places. It had already had a chequered fate during this century. It is the sole surviving astronomical instrument in the collection of Mr. Jasim al-Homaizi for he carried it with him when he fled Kuwait in 1990.

Description

The throne bears on the front and back beautifully-executed images of two feline faces. Are these leopards or tigers or lionesses, or could they be happy cats watching out for the birds on the rete? The necks of the felines lead into a circular frame outside which simple leaf and twirl patterns complete the outer parts of the throne. There are two small lobes, a larger one formed by the circular frames for the felines, and a very small one on either side of the central part. The ensemble is bevelled in the tradition of the 10th century. The shackle is trowel-shaped and is attached to a circular ring. The rim is riveted to the back, with three rivets on the right levelled to the surface of the rim and the four on the right unlevelled—it seems that the latter might be replacements; certainly the back has separated from the rim at the bottom, where there are no rivets. The scale on the rim is divided 5°/1°-5° (without tens and hundreds), and the radial markers for each 15° are marked with two dots. The mater bears astronomical markings—see below.

The rete is a masterpiece. The equinoctial bar is rectilinear, its upper side serving as the axis. A series of designs together constitute the solstitial axis: there is a quatrefoil (unique on early Islamic instruments except for those based on this one but a popular feature on early European astrolabes—see below), an inverted heart-shaped frame to which are attached two wing-shaped pointers, a circular frame including a kind of "Smiley-type" frame intended to represent the lunar mansion *al-hanʿa*, although this is not stated,[114] and two curved "table-legs" supporting

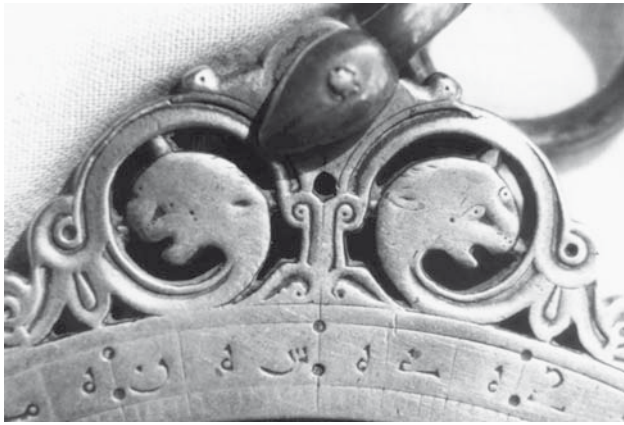
[112] On Hibatallāh see Rosenthal, "Al-Asṭurlābī and as-Samawʾal on Scientific Progress", and for one of his instruments, see King, "*Zīj al-Ṣafāʾiḥ*".

[113] See Kennedy & Kennedy, *Islamic Geographical Coordinates*, pp. 55-56 and 680-681, and also King, *al-Khwārizmī*, p. 2.

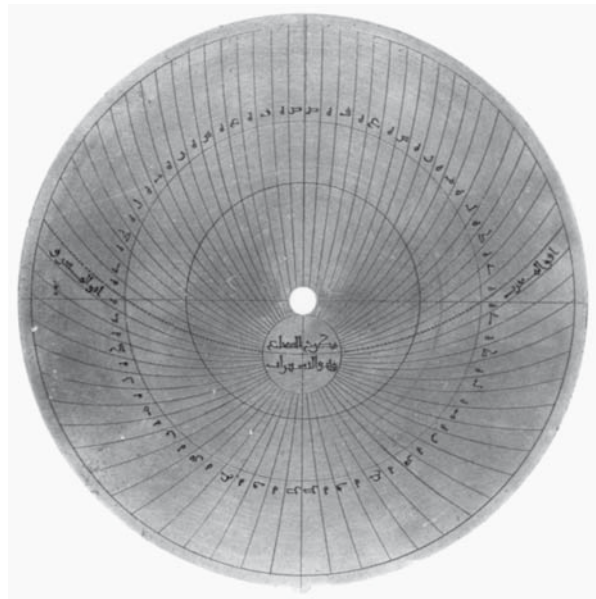
[114] Compare, for example, the representation on the astrolabe dated 618 H [= 1223/24] featured in Gunther, *Astrolabes*, I, pl. XXV (no. 5), also in **Fig. XVII-1.4**.

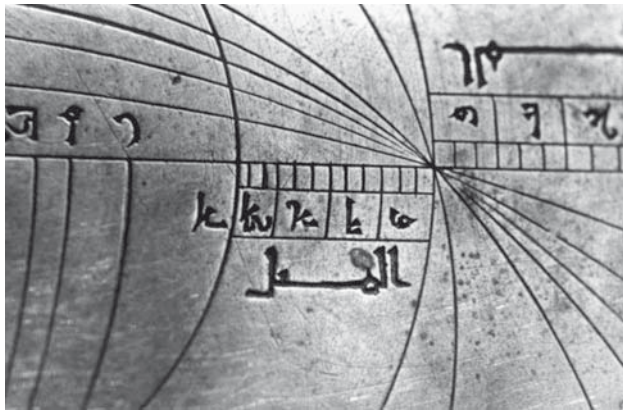
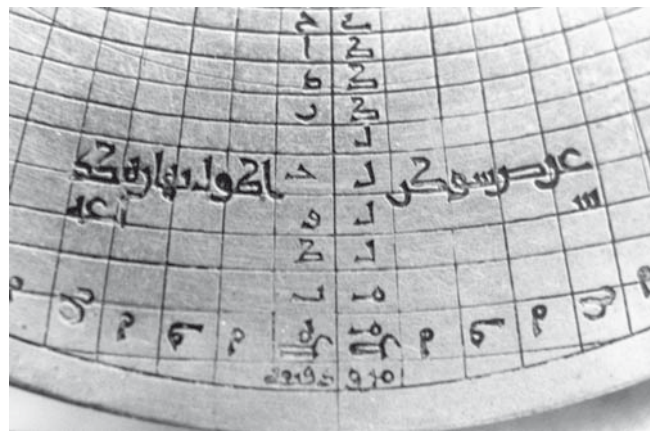
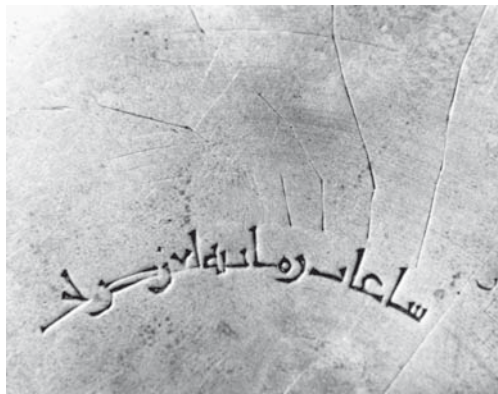
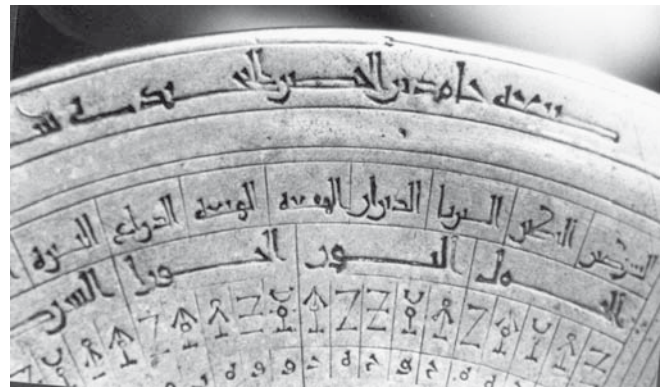
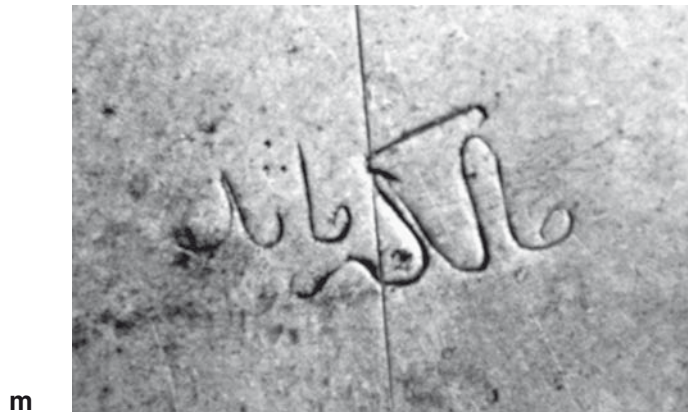
a

b

Figs. 9a-m: The magnificent astrolabe of al-Khujandī (#111). [All full photos courtesy of the owner, details by the author.]
(a) The front.
(b) The back.

c

d

e

f

(c) The feline figures on the throne.
(d) The pointer for the star labelled *min jasad qayṭus*.
(e) The markings for latitude 42° on the mater.
(f) The plate for casting the rays at latitude 33°.

(g) Part of one of the declination scales on the plate of horizons.
(h) The inscription on the plate for converting celestial coordinates.
(i) The horary quadrant for latitude 33° on the back.
(j) The date.
(k) The signature.
(l) The horse.

m

(m) The owner's mark, as yet not interpreted.

the middle of the long lower equatorial bar. See the illustration in **Fig. 1** to the preamble to this study. There is a thin solstitial bar between the lower equatorial bar (which is outside the equator) and the northern ecliptic and a thin slightly trapezoidal frame connecting the latter to the central disc. The scale of the ecliptic circle is divided 6°/3°-6° within each sign (Pisces is rendered as *al-ḥūt*).

The presence of a quatrefoil as a decorative motif on this astrolabe from 10th-century Iraq is of prime importance for the early history of the principal motif of Gothic art and architecture.[115] It is not a specifically Islamic motif, being found in the Islamic world mainly on architecture of Byzantine origin or inspiration: for example, a quatrefoil, very botanical in appearance, is found as decoration on a house in Baqouza in Syria which goes back perhaps as far as the 4th century. Another occurs on an early-9th-century Syrian frieze, but its appearance there is partly explained by the accompanying hexafoil—both are used as floral motifs.[116] Yet it occurs on al-Khujandī's astrolabe and on various other Eastern Islamic astrolabes based on al-Khujandī's distinctive rete design.[117] It also occurs on an Andalusī astrolabe dated 638 H [= 1240/41],[118] and on one of the earliest surviving European astrolabes, from Catalonia *ca.* 1300.[119] It seems clear that the presence of the quatrefoil on this European astrolabe in an

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[115] Thus, for example, we find in M. Stafford & D. Ware, *Dictionary of Ornament*, p. 176: "Quatrefoil: ... A characteristic device in Byzantine decoration and Gothic tracery and carving, that regained popularity in the Gothic revival. Sometimes stated to be based on the four-leafed clover; reliable authorities believe the quatrefoil to be a strictly Christian motif—a form of Greek cross with rounded ends, or of the nimbus with four arcs representing the four Evangelists. ... "

[116] On the house in Baqouza see *Dict. arch. chrét.*, II:1, cols. 469-478 (by H. Leclercq) especially cols. 473 and 478 (after Vogüé). On the 9th-century Syrian frieze see *Washington 1985 Syria Exhibition Catalogue*, pp. 514-515 (no. 256), with illustration.

[117] Gunther, *Astrolabes*, I, pp. 114-116 and pls. XXII=XXIII (no. 3)—dated 374 H [= 984/85]; the rete, however, is a later replacement datable to *ca.* 1100); and *ibid*., I, pp. 118-120 and pls. XXV-XXVI (no. 5)—dated 618 H [= 1223/24].

[118] #154—*Ibid*., I, p 300 (no. 154) and pl. LXVII (misdated to 1747!).

[119] #162—*Ibid*., II, pp. 306-309 (no. 162), with illustrations.

identical position to that on al-Khujandī's astrolabe was inspired by Islamic models. This raises some interesting questions that should be pursued by art historians: see further **XVII**.

The stars represented on the rete have been chosen so that the ensemble is roughly symmetrical about the solstitial axis. Six of the star pointers are in the form of birds' heads, thirteen dagger-shaped, and the remainder—some seven in number—are like either claws or teeth. The ensemble presents a most pleasing aspect. It is worthy of note that no bird is used to represent Vega (*al-nasr al-wāqiʿ*)—it has been argued elsewhere that this is a motif adopted in the 8th and 9th centuries by the Muslims from Byzantine astrolabes but not attested on surviving Islamic astrolabes until *ca*. 1200, and later becoming quite popular in the Islamic East.[120]

The 33 stars represented on the rete are with few exceptions standard astrolabe stars. They are as follows (arranged in order of increasing right ascension):

min jasad qayṭus	bird's head at left end of circular bar
raʾs al-ghūl	
ʿayn al-thawr	
al-ʿayyūq	
rijl al-jawzāʾ	
surrat al-jawzāʾ	
yad al-jawzāʾ	

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al-yamāniya	

[*a*]*l-shiʿrā al-shaʾāmiya*	
raʾs al-shirāʿ	
ʿunuq al-shujāʿ	(position problematic)
qalb al-asad	
rukbat al-dubb	
janāḥ al-ghurāb	bird's head at right end of circular bar

---

al-simāk al-aʿzal	
dhanab ṭaraf al-dubb	bird's head on west equinoctial bar
al-rāmiḥ	
ʿurqūb al-ʿawwā’	(on inner rim of ecliptic)
al-munīr min al-fakka	
ʿunuq al-ḥayya	bird's head inside ecliptic

[120] The earliest representation in this form—apart from an Islamic astrolabe datable *ca*. 800 and the sole surviving Byzantine astrolabe dated 1062—is on the instrument mentioned in n. 114 above.

mankib al-jāthī	on right wing of heart-shaped” frame (position problematic)
qalb al-ʿaqrab	
raʾs al-ḥawwā’	
al-wāqiʿ	small hole
al-ṭāʾir	
dhanab al-dulfīn	bird’s head inside ecliptic
dhanab al-dajāja	
janāḥ al-dajāja	on left wing on heart-shaped frame
dhanab al-jady	
mankib	
kaff al-khaḍīb	bird’s head on left of equinoctial bar
surrat al-faras	
dhanab qayṭus	

The positions of the stars, with two exceptions noted above, are very accurate for the epoch in question (Burkhard Stautz). The position of Regulus is roughly Leo 15°, which corresponds to the early 10th century. It should be borne in mind that contemporary star catalogues gave a longitude for Regulus that was almost $^1/_2$° too small, so that an early dating by this method is perhaps inevitable. (Stautz presents graphics showing the correspondence of the star-positions with the Ptolemaic values adjusted to 984 for the *Mumtaḥan* value of the precession.) On the back of the rete, there are markings for the two base diameters.

The mater and five plates are expertly engraved. The mater and seven sides serve specific individual latitudes, as follows (*ʿarḍ* — *aṭwal nahārihi* — *sāʿa* — *daqīqa*):

1a	21°	13;18^h	[0]
1b	27	13;44	[0]
2a	30	13;58	[0]
2b	33	14;13	[0]
3a	36	14;30	[0]
3b	39	14;48	[0]
M	42	15; 7	[-1]

The markings in addition to the labelled curves for the seasonal hours are of three main kinds. Firstly, the mater for 42° bears altitude circles for each 3° labelled for each 6° in an annular scale between the two outer circles up to 48° (the odd altitude circles are omitted within the annulus) and then in a special scale up the meridian to 84°, the zenith being labelled 90°. Secondly, the sides for 21°, 30° and 39° have altitude circles for each 3° and azimuth circles for each 5° below the horizon. The former are labelled as on the mater and the latter are labelled for each 10° below the horizon and the “crescent”. There are no azimuth circles inside the

"crescent". Thirdly, the sides for 27°, 33° and 36° bear altitude circles for each 3° labelled as on the mater and azimuth circles for each 5° above the horizon. The latter are labelled for each 10° between the horizon and the altitude circle for 6° (the circle for altitude 3° has been omitted) continuing around the outside of the altitude circles to the meridian. There are no azimuth circles for altitudes above 84°. In addition, there are labelled curves for the hours since sunset. The distinctive altitude scales, which are ingenious although they to some extent obscure essential markings, are found not only on all of the plates but also on certain later instruments in the Khujandī tradition. The ends of the horizon on all these plates are marked *al-maghrib* and *al-mashriq*.

The lengths of longest daylight correspond to recomputation only with the Ptolemaic value of the obliquity! They are 1-3 minutes larger than values computed with obliquity 23;35° or 23;33°. The last value should actually be 15;8°. All this might be considered a lapse of integrity by the scholar most famed in the history of astronomy for his achievements in the measurement of the obliquity.

For which localities were the plates intended? The one for 21° was doubtless supposed to serve Mecca. This parameter and two others, 21;40° and 21;30°, were widely accepted already in the 10th century; the accurate value is 21;26°. The plate for latitude 30° would serve Cairo, but that would be of little interest to an astronomer in Iraq or Iran. Those for 33° and 36° would serve Baghdad and Rayy. But in preparing plates for each 3° of latitude from 27° to 42° al-Khujandī may well have been aiming at achieving a modest measure of universality for his instrument, a supposition confirmed by his choice of intermediate latitudes on the plate of horizons (see below).

Plate 4a bears markings stated to be for latitude 66;27°, where "the maximum length of daylight is 24 hours": see **Fig. XVI-10.2**. Implicit here is the obliquity 23;33°, the second result of the astronomers of al-Maʾmūn (see, for example, **I-9.1**). There are altitude circles for each 3° and azimuth circles for each 5°. The meridian altitude scale runs in 3°-intervals from 3° to 66° and the zenith is marked 90°. Another scale runs along the meridian below the horizon in 3°-intervals from 3° to 45° and a final value of 47;6° at the winter solstice circle. This arc of depression corresponds to the maximum elevation of the sun above the horizon, namely twice the obliquity. The purpose of this scale is not clear. The azimuths are labelled for each 5° around the outer rim and again below the lower part of the horizon. The right-hand side of the horizon is marked *ufuq al-maghrib*, the left-hand side *ufuq al-mashriq*, and the prime vertical is dotted.

Plate 4b serves both the latitude of the equator "where the maximum daylight is 12 hours" (*khaṭṭ al-istiwāʾ sāʿātuhu yb*) and latitude 90° "where (it) is six months" (*ʿarḍ ṣ ṭūl nahārihi w ashhur*): see **Fig. XVI-10.1**. On the upper half are altitude circles for each 3° for latitude 0° and on the lower half the hour-lines for latitude 0° (each hour being 15° long throughout the year). The former are labelled between the two outer circles and then up the meridian to the zenith. Superposed on both of these sets are the markings for latitude 90°, which are simply altitude circles for each 3° above the horizon (which is identical with the equinoctial circle) up to 60°. These are labelled along the upper meridian. The circle for altitude 24° is very close to the circle for the summer solstice (which should correspond to altitude 23;33°). The plates for latitudes 0° and 90° and the horizon for latitude 75° on the plate of horizons (see below)

were no doubt intended for purely didactic purposes. Interesting things happen in the sky at such latitudes, and these plates could be used to demonstrate them.

Plate 5a is marked with half-horizons for 20 different latitudes arranged around the plate in 4 groups of five. The latitudes served are:

15	25	32	38	47
18	28	34	40	50
20	29	35	41	53
23	31	37	44	55

which together with those represented on the other plates constitute a fairly complete set for every 2° or 3° from 15° to 55°. In addition there is a full horizon for latitude 75°. On each of the four axes there is a declination scale on either side of the equinoctial circle divided 6°/2-6° up to 18° and then 6°/2° up to a maximum labelled 23;33°. al-Khujandī here confirms the parameter attested already on his ecliptic plate.

Plate 5b serves to facilitate the otherwise laborious computations relating to the astrological doctrine of casting the rays and is so designated in the cartouche (*maṭraḥ al-shuʿāʿ wa-huwa ʾl-tasyīrāt*). The plate serves a specific latitude which is not stated; by inspection, however, it is found to be 33°, serving [Baghdad]. *It is the first attestation of such plates*, which were used into the Renaissance.[121] The curves are the projections of the great circles through the north and south points of the horizon for each 5° on the equator and are labelled around the outside of the equatorial circle. The ends of the horizon are marked *ufuq al-maghrib* and *ufuq al-mashriq*.

The back bears altitude scales divided 5°/1°-5°. The upper left quadrant bears horizontal parallels for each 1° of argument on the quadrant scale up to a maximum that cannot be determined since the upper markings have worn away. In the upper right there is an horary quadrant for latitude 33° (*sāʿāt zamāniyya li-ʿarḍ lj*). The ecliptic scale on the vertical radius spans only about one-half of the length of the axis. The first and second hour-curves are smooth but the four upper ones, and the ecliptic scale, are barely visible, having been worn away by the alidade. There appear to be quarter-circles only for each 30° of solar longitude. The lower back bears mainly astrological information. An inscription reads:

"The limits of the Egyptians and the faces and lords of the triplicities."

The scales, numbered here from the outside, record:

(1) the names of the 28 lunar mansions;
(2) the names of the 12 signs;
(3) indications of the sun, moon and planets which are the lords of the limits;
(4) the length of the limits in degrees;
(5) the lords of the faces;
(6) the numbers 10—20—30 (in *abjad* notation) for the divisions of the faces within each sign;
(7/8) the lords of the day and night and the companion for each sign.

[121] On this concept see further the EI_2 article "Tasyīr" by Otto Schirmer (taken over from EI_1), and especially North, *Horoscopes and History*, pp. 1-69. I cannot say who was the first to introduce these markings.

Symbols ultimately of Hellenistic origin are used for denoting the sun, moon and planets in scale 3; elsewhere, as in scales 5, 7 and 8, the names are abbreviated by the last letter of the Arabic name, thus *sīn* for *shams* (Sun), *rā'* for *qamar* (Moon), *dāl* for *ʿuṭārid* (Mercury), *etc*. The scale for shadows to base 12 on the rim of the lower right quadrant is marked *aṣābiʿ al-ẓill* and divided 5/1-5 up to 60, although the subdivisions peter out after 50 units. An inscription on the rim of the lower left quadrant reads clearly and simply:

صنعه حامد بن الخضر الخجندي سنة شعد للهجرة

"Constructed by Ḥāmid ibn al-Khiḍr al-Khujandī
in the year 374 Hijra [= 984/85]."

There is another inscription in a later hand just below the centre—see below.

The alidade is a later replacement—see below—but the horse and perhaps even the peg appear to be original. A realistic horse's head has a thin rectangular plate attached through its neck, the plate fitting into a hole in the stem of the peg, which has a low, wide cylindrical head and a bulbous protrusion at the other end. The horse's head can be rotated by 90° about the stem of the plate so that it either stands erect on the back of the instrument or lies flat on it. (I have not seen this feature elsewhere.)

Later additions and replacements:

1) There is another inscription in a later hand just below the centre of the back (see **Fig. 9m**). It appears to read: *mālikuhu m-ʾ-th-d*, "its owner is ???". The name is unintelligible to me, being neither Arabic not Persian. The three dots on the *thāʾ* may not be original. The dubious name could be read as *qāʾid*, but this is not a personal name. Another possibility is *fāʾid*, which is a personal name (at least in modern Kuwait!), but this seems an unlikely solution.

2) The alidade is a later replacement with crudely marked scales and inscriptions. There is a scale for the signs of the ecliptic on one side (for the solar quadrant) and another non-linear sexagesimal scale on one edge of the other. On the other edge, there is a scale that is unintelligible to me, with markings (in *abjad*) that seem to indicate 70/20, 4/10 and 2/70.

Concluding remarks

Certain distinctive features of al-Khujandī's astrolabe, such as the quatrefoil and the special frame for the lunar mansion *al-hanʿa*, occur on various later Islamic instruments, and it is clear that these were influenced by his workshop. Three examples are:

- ❖ the replacement rete (datable by the star-positions to *ca*. 1100) for the astrolabe (#3) made by the two sons of Ibrāhīm al-Iṣfahānī in the same year as the astrolabe of al-Khujandī (not previously recognized as a replacement) (see now **10** and **Fig. XVII-1.2**);[122]
- ❖ the rete on an astrolabe (#2557) by Badr, the *mawlā* of Hibatallāh, in 525 H [= 1130/31] (see **Fig. XVII-1.3**);[123] and

[122] #3—Gunther, *Astrolabes*, I, pp. 114-116 (no. 3), now in **10**!

[123] #2557—Illustrated in Sabra, "Exact Sciences", p. 129. To be featured in the forthcoming catalogue of the Collection of the Adler Planetarium in Chicago.

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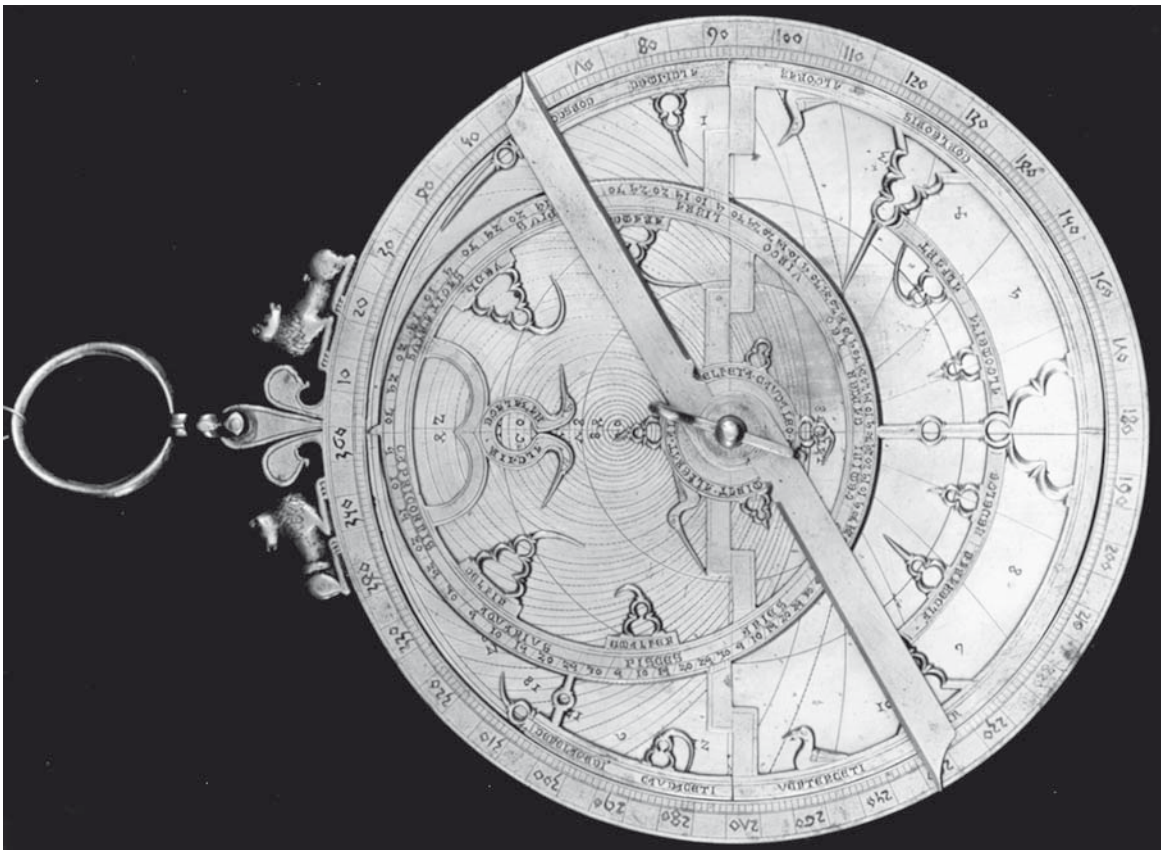
- ❖ the rete on the geared astrolabe (#5) by Muḥammad ibn Abī Bakr al-Isfahānī in 620 H [= 1223/24] (see **Fig. XVII-1.4**);[124]

as well as on several later pieces of Iranian provenance (see also **XVII**).

In particular, there is one 14th-century French astrolabe (#2041) on which the throne and the upper part of the rete bear suspicious resemblance to that of al-Khujandī: see **Fig. 9n**. The lower part of the rete is modelled after the *miḥrāb*s of 11th-century Andalusī retes: compare **Fig. 9o**.

10 An astrolabe by Aḥmad and Muḥammad, sons of Ibrāhīm al-Iṣfahānī, dated 374 H and fitted with a replacement rete datable *ca.* 500 H

International Instrument Checklist #3.
Oxford, Museum of History of Science: ICC 3. "Purchased by Dr. Lewis Evans for £250 in April 1919 through Percy Webster from Professor Y. Daweed" (Gunther).
Brass. Diameter: 132 mm.
Bibliography: Gunther, *Early Science in Oxford*, II, p. 199, also illustration of the front opp. p. 188; *idem*, *Astrolabes*, I, pp. 114-116, with a complete set of photos in pls. XXII and XXIII and a creditable description; Mayer, *Islamic Astrolabists*, p. 36; Destombes, "Astrolabe carolingien", p. 14; *London SM 1976 Exhibition Catalogue*, p. 103; *Rockford TM Catalogue*, p. 22; Torode, "Mathematical System", p. 65 (unreliable, but notes a problem with the rete); Stautz, *Mathematisch-astronomische Darstellungen auf mittelalterlichen Instrumenten*, pp. 48-50 and 186, on the star-positions on the rete; **XI-9.3** on the trigonometric quadrant; and **XVII-1** on the quatrefoil. The information on the latitudes of the plates given in King, "Geography of Astrolabes", p. 22, is incorrect, and the conclusion on p. 9 drawn from this incorrect information is nonsense: see the preamble to **XVI**.

This instrument, the first Islamic astrolabe described by Gunther because it was the earliest "Persian" instrument known to him, has not previously been recognized as a composite piece. The rete is clearly a replacement because the star-positions correspond to *ca*. 1100. There seem to be two layers of additional markings: the gazetteer on the mater and the astrological scales on the back. A new examination of the instrument might settle this.

The throne is most unusual: it is high and built up with circular arcs. The suspensory apparatus, a shackle with triangular bases and a ring, appears to be original although both parts are unduly large. The scale on the rim is divided 5°/1°-5° (labelled in full) and the rim is rather wide. There is a peg at 0.79 of the radius below the centre of the mater. The back is now loose and attached only at the utmost part of the throne; how it was originally attached securely to

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Fig. 9n: The rete of this 14th-century French astrolabe (#2041) bears some relationship to that of al-Khujandī. Notice the two dogs on the throne, on either side of the very French *fleur-de-lys*, and the various birds. The original quatrefoil is here reduced to a circular frame. [Courtesy of the Museum of the History of Science, Oxford.]
Fig. 9o: Note the *miḥrāb*-shaped frames on the rete of this astrolabe made by Ibrāhīm ibn Saʿīd al-Sahlī in Toledo in 460 H [= 1068] (#118). For the back of this astrolabe see **Fig. XIIIa-10.2b**. [Courtesy of the Museum of the History of Science, Oxford.]

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[124] Gunther, *Astrolabes*, I, pp. 118-120 (no. 5).

Fig. 10a: The front of an astrolabe by Aḥmad and Muḥammad, sons of Ibrāhīm al-Iṣfahānī, dated 374 H [= 984/85] and fitted with a replacement rete datable *ca*. 1100 (#3). The historical importance of this piece is by no means lessened by the fact that it is a composite piece. One may wonder whether the original rete was replaced because it was not attractive enough. [**Figs. 10a-c** courtesy of the Museum of the History of Science, Oxford.]
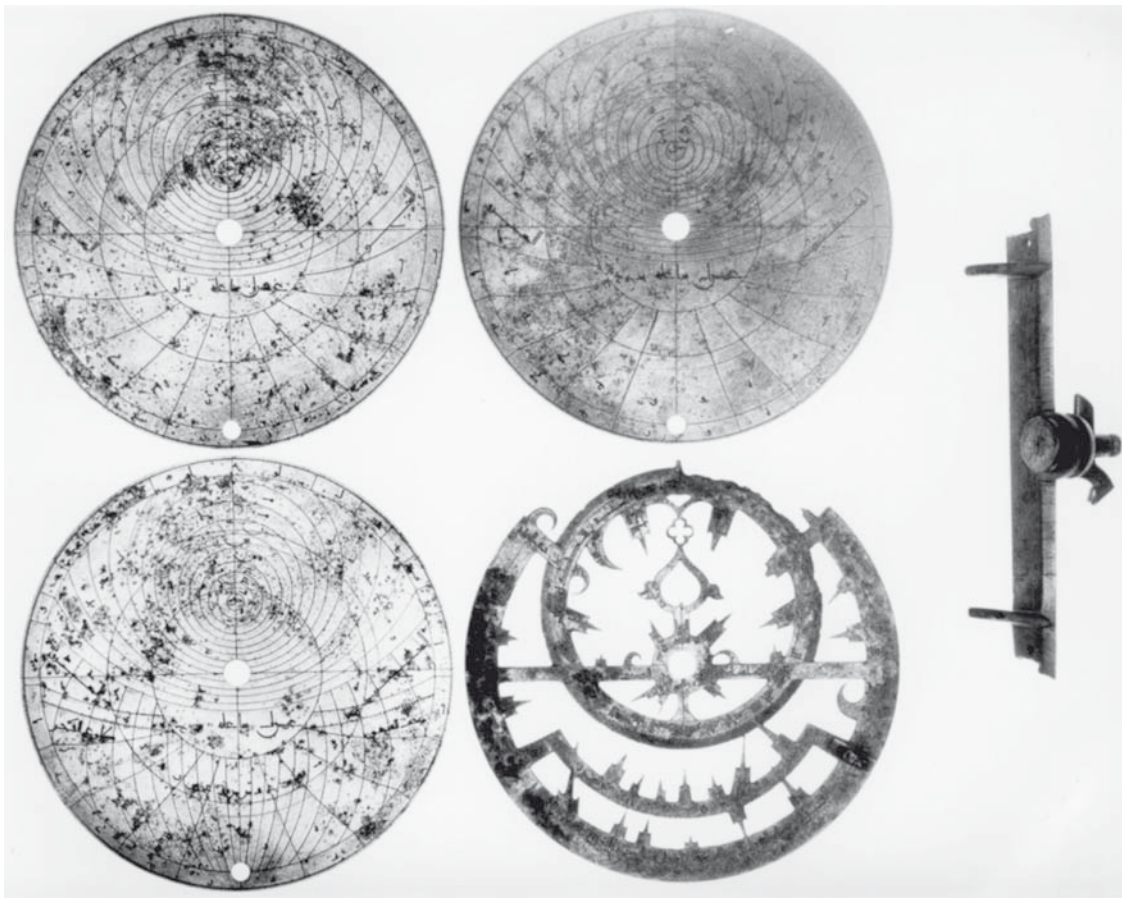
Fig. 10b1: The plates for five latitudes and the plate of horizons, as well as the front and back of the rete (#3).

the mater is by no means clear. The mater bears markings that appear to be later—see below.

The rete is a replacement from *ca*. 1100 and is discussed below.

The three plates bear altitude circles for each 6° of altitude and curves for the seasonal hours. The one for latitude 32°, doubtless intended to serve Isfahan where the instrument was probably made, bears additional azimuth circles for each 10° below the horizon. An altitude scale is engraved on the rim of each plate, but less than one-quarter of the rim is visible when the rete is laid on the plate, so this was not such a good idea. Another unusual and distinctive feature is the markings for the hours around the circumference. The plate for 32° also bears circles for twilight, which correspond to a solar depression of 18°. The various latitudes served by the plates and the associated lengths of longest day are:

1a	30°	13;58^h	[0]
2a	32	14; 8	[0]
2b	33	14;13	[0]
1b	36	14;30	[0]
3a	37	14;36	[0]
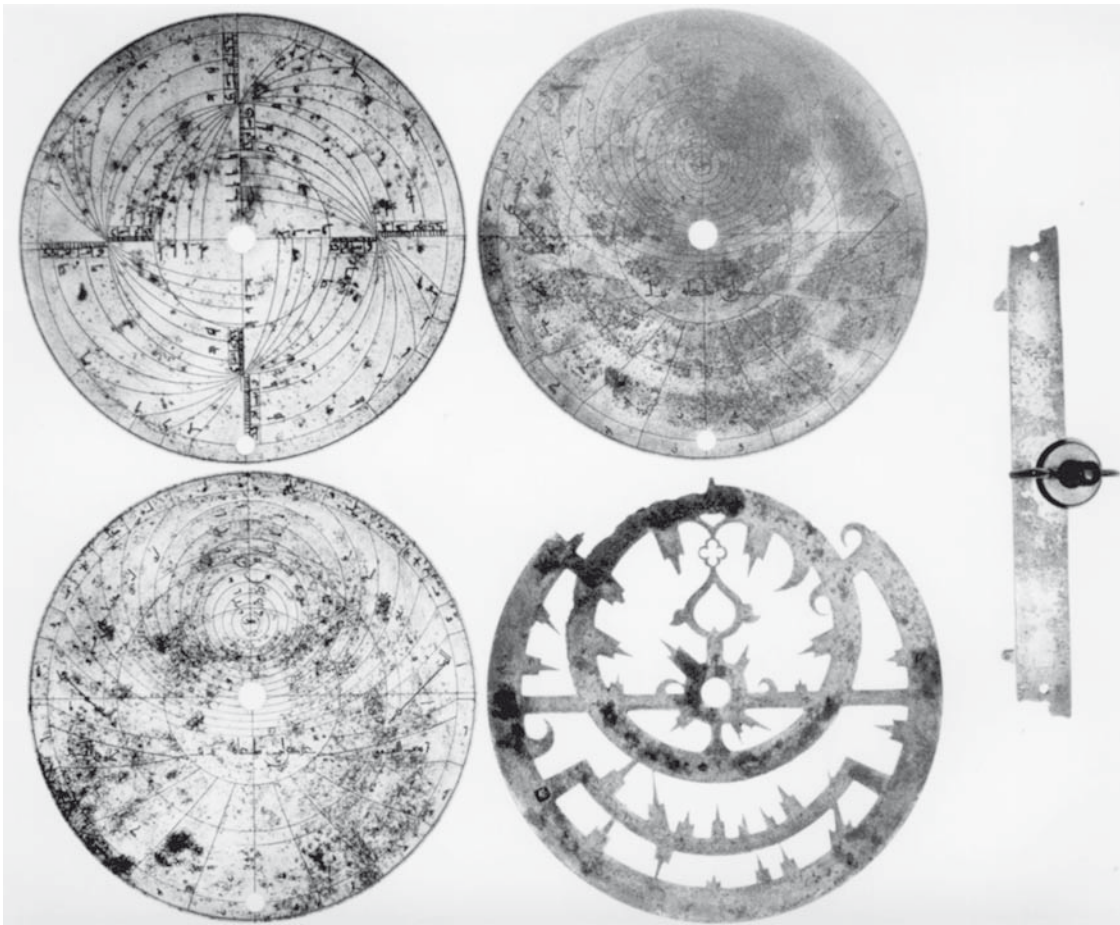
Fig. 10b2.

The lengths of maximum daylight correspond to an obliquity of 23;51°. Plate 3b is a plate of horizons similar to that of al-Khujandī, with declination scales up to 24°.

The back bears two altitude scales divided 5°/1°-5°, and a shadow-scale on the lower right rim (divisions unclear) marked *aṣābiʿ al-ẓill*. Of the other markings only those in the upper left quadrant and the inscription are original. The empty space on three quadrants has been filled by the same person who added the replacement rete.

The upper left quadrant bears a trigonometric grid with parallels for each 5° of arc and corresponding quarter-circles (that is, with radii R sin (5i), where R is the radius of the quadrant and i = 1, 2,..., 17). Perhaps the most unusual feature of the whole instrument is the scale with width corresponding to about 5° on the outer quadrant to the right of this quadrant. It shows the sines to base R of each 5° of argument, and its use is hinted at in the inscription written along it: *al-sāʿāt al-zamāniyya li-kull ʿarḍ*, "the seasonal hours for all latitudes". This remark confirms the origin of the sine quadrant as a device for calculating the time from the solar altitude by means of the standard approximate formula—see **XI-9.3**.

Fig. 10c: The back (#3). The later astrological markings are easily distinguished from the original markings. Note that the sine quadrant is labelled "(for finding) the hours for all latitudes", reflecting its origins.

The inscription below the horizontal diameter translates:

بسم الله وبعون الله باليمن والدولة والإقبال والسعادة ألف هذا الأصطرلاب أحمد ومحمد ابنا إبراهيم
الأصطرلابيين (!) الإصبهانيين (!) سنة اربع وسبعين ثلثمائة
ساعات زمانية لكل عرض

"In the name of God, and with the help of God, for well-being, good fortune, success, and happiness (*bi-'l-yumn wa-'l-dawla wa-'l-iqbāl wa-'l-saʿāda*), this astrolabe was composed (*allafa*) by Aḥmad and Muḥammad," the two sons of Ibrāhīm, the two astrolabists of Isfahan," in the year three hundred and seventy-four (Hijra) [= 984/85]."

The use of the verb *allafa* instead of *ṣanaʿa* or *ʿamila* is unique on known Islamic pieces, but compare the Latin *composuit*, which occurs on a single early European instrument (see **Fig. XIIIa-10.5c**).

Later replacements and additions

The rete is elegant, vaguely symmetrical and without zoomorphic pointers. The equinoctial bar is rectilinear and is slightly thicker outside the ecliptic on the right. The equatorial frame is supported only at the ends and the pointer for *al-kaff al-jadhmāʾ* goes across it, and that for *raʾs al-shirāʿ* points outwards from it. The circumferential frame is unduly thick to conform with the unsual feature of the plates—see above. There is a heart-shaped frame and a quatrefoil between the centre and the winter solstice on the ecliptic. In short, there are several features that are reminiscent of the retes of al-Khujandī—see **9**—and Badr—see **Fig. X-4.1.1**. However, any suspicion that it is either by Badr or by his master, Hibatallāh, is not supported by the fact that the inscriptions are rather awkward (for example, the word *al-wāqiʿ* is split and the name *dhanab al-jady* is written radially) and that the astrological tables on the back, which are due to the same person, are not drawn with the utmost care that we can associate with these two individuals.

The divisions on the scale of the ecliptic are not clear on the photo available to me (in places 10°-divisions are visible), and the ring is damaged on the upper right. Most of the pointers are dagger-shaped, the remainder are shaped like a tiger's claw (3) or wings (2). The rete is corroded, particularly in the upper right, and several of the star names have been obliterated (marked with black dots • below). The positions correspond closely to *ca*. 1100 (Stautz; Torode arrives at the date 1104 with standard deviation 210 but using several incorrectly-identified stars). The stars represented are the following:

jabhat qayṭus	*janāḥ al-ghurāb*	
al-ghūl	————————	
al-kaff al-ja[*dh*]*māʾ*	[*al-simāk*] *al-aʿzal*	
ʿayn al-thawr	••	equinoctial bar
al-ʿayyūq	••	equinoctial bar

rijl al-jawzāʾ	A	••	outer rim
yad	A	*al-rāmiḥ*	
rijl al-jawzāʾ	B	[*al-fakka*]	
yad al-jawzāʾ	B	[*ʿunuq al-ḥayya*]	
————————		[*qalb al-ʿaqrab*]	
al-hanʿa		[*mankib al-jāthī*]	compare al-Khujandī
————————		[*raʾs al-ḥawwāʾ*]	
al-yamāniya		————————	
al-shaʾāmiya		*al-wāqiʿ*	small hole
raʾs al-shirāʿ		*nasr al-ṭāʾir* [*sic*]	
al-ṭaraf attached to outer rim of the		*janāḥ al-dajāja*	
ecliptic—compare al-Khujandī		*dhanab al-dulfīn*	
al-fard		*ridf*	
rukbat al-dubb		*dhanab al-jady*	
qalb al-asad		•	claw on ecliptic
mankib			
al-khaḍīb			
dhan[*ab qay*]*ṭus*			
[*surrat al-faras*]			

The empty space on the three quadrants of the back has been filled with annular scales of astrological information as follows, reading from the outside inwards:
(1) the signs of the zodiac, with standard names;
(2) symbols for the lords of the limits;
(3) the length of the limits in degrees;
(4) symbols of the lords of the day and night and the companion for each sign.

The scales are squeezed uncomfortably in the space available on these quadrants, and the divisions for the signs and limits are not carefully drawn. This argues against the markings being the work of Hibatallāh or Badr.

The geographical gazetteer for 32 localities engraved on the mater in a rounded *naskhī* script (see **Fig. 10d**) and *seems* to be original. The outside of the annular frame for the entries would otherwise have encountered problems on either side of the peg for the plates. It is not the fact that it is in *naskhī* script that disturbs me, but rather that the script is entirely different from both the original and the secondary *kūfī* script elsewhere on the piece. In any case, the gazetteer is of considerable historical interest. The data are from the 10th or 11th century and are not found elsewhere in this combination. They *could* have been inserted on this astrolabe as early as the 10th or 11th century (the fact that they are in *naskhī* script does *not* argue against this), perhaps *ca*. 1100, when the replacement rete was added. The fact that some of the data are corrupt argues for a later dating (since people generally cared less), but the gazetteer cannot have been added as late as, say, the 14th century, because by then other geographical data would have
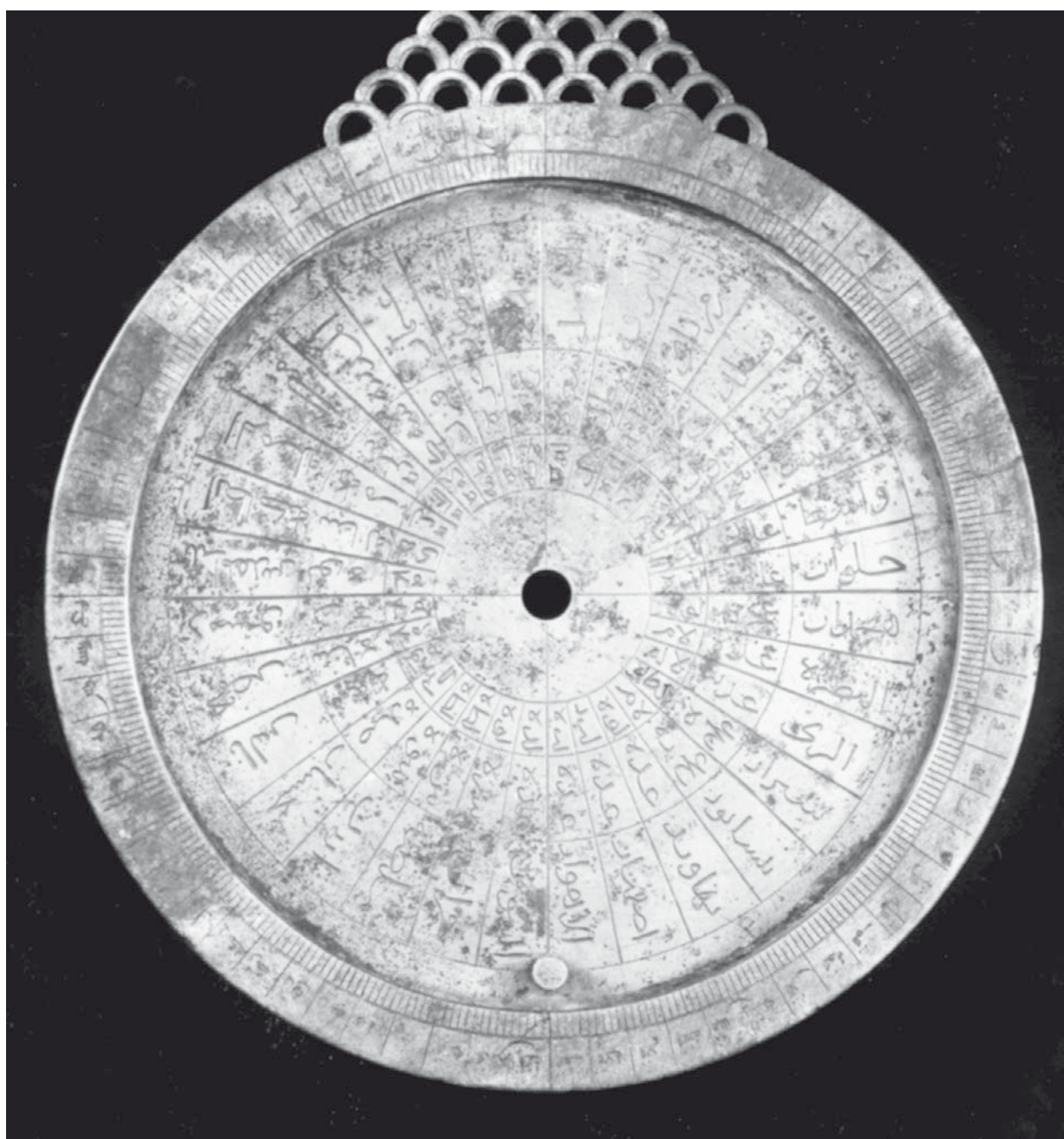
Fig. 10d: The gazetteer on the mater.

have been preferred. The following is a preliminary edition of the data, which would eventually repay further investigation.

Notes: For the context and the use of abbreviations see Kennedy & Kennedy, *Islamic Geographical Coordinates* (hereafter K&K). KHW denotes the al-Khwārizmī tradition, exemplified by KHU and KHZ. SUH for Suhrāb and YUN for Ibn Yūnus are dependent on KHW. ATW is ATH FID in K&K, representing the enigmatic *Kitīb al-Aṭwīl wa-ʻl-ʿurūḍ*, whose date is still a matter of debate (see **VIIc-4c**). BIR is al-Bīrūnī, independent of KHW and ATW. The later Iranian tradition is dominated by the ATW tradition: TUS for al-Ṭūsī, ULG for Ulugh Beg, and TMR for an anonymous 15th-century Timurid source identified in my *Mecca-Centred World-Maps*.

Locality		**L**	**ϕ**	**Comments**
1	Mosul	69; 0	35;[30]	minutes of ϕ unclear; as here restored corresponds to KHW
2	Kufa	69;30	31;30	KHW has L/ϕ: 69;30°/31;50°; ATW has **69;30°/31;30°**
3	Samarra	69;45	34; 0	as in KHW
4	Balad	68;30	36; 0	KHW has L/ϕ: 68;45°/36;20°; this combination of L/ϕ not attested elsewhere
5	Nisibin	66;30	36; 0	L problematic; KHW has ϕ: 36;0°; ATW has 37;0° (accurately 37°5′)
6	Hit	68;30	33;15	as in KHW
7	Wasit	71;33	32;20	KHW, also ATW, has L/ϕ: 71;30°/32;20°, but BIR has L: 71;32° (perhaps from a confusion between the minutes of L and the degrees of ϕ); all this does not explain the 33 in 71;33°
8	Hulwan	71;45	34; 0	as in KHW
9	Hamadhan	73; 0	36; 0	as in KHW
10	Basra	74; 0	31;40	KHW has L/ϕ: 74;0°/31;0°; no sources have ϕ: 31;40°, so that the 40 is probably an error for 0; ATW has ϕ: 30;3° (accurately 30°30′)
11	Rayy	74;[0]	**[35];35**	very confused; gazetteer has L/ϕ: 74;17/31;35, possibly to be restored in this way (note that "31" and "0" have similar forms in *abjad* notation)—note (restored) new value of ϕ. KHW has L/ϕ: 75;0°/35;45°, with 74;0° as a variant (not attested elsewhere); SUH has 75;0°/35;35°; ATW has 76;20°/35;35°; TMR confused.

12	Shiraz	78; 0	**29;36**	KHW has L/ϕ: 78;0°/32;0°; SUH has 78;0°/31;0°; note new value of ϕ, which first appears in BIR FID (al-Bīrūnī as quoted by Abu ʻl-Fidāʼ) although BIR has 29;35°; the accurate value is 29°38′(!); ϕ: 29;36° used by TUS/ULG/TMR, *etc*.
13	Nishapur	78;15	31;40	KHW has L/ϕ: 80;45°/37;0°; SUH has 81;45°/36;0°; these problematic values are not attested elsewhere, even allowing for the possibility of an error for 36 or 37 in the degrees of ϕ; no other sources have L less than 80° or ϕ with 40 minutes
14	Nihawand	74; 0	36; 0	as in KHW; ATW has ϕ: 34;20° (accurately 34°13′)
15	Isfahan	74; 0	**32;30**	KHW has L/ϕ: 74;40°/34;30°; SUH has 74;50°/34;0°; the accurate value of ϕ is 32°41′; ATW has 76;40°/**32;40°** (!); BIR has ϕ: 33;30°, which SNJ converts to 32;30° (by misreading from a map); otherwise ϕ: 32;30° not attested in early sources; many later sources have ϕ: 32;25°, as for example, TMR with L/ϕ: 76;40°+10°/32;25°.
16	Ahwaz	74; 0	32; 0	KHW has L/ϕ: 75;0°/32;0°; L: 74° corresponds to the 84° in PTO reduced by 10° difference in the prime meridians
17	Sus	74; 0	34; 0	as in KHW (correcting L in K&K from 84;0° to 74;0°); ATW has ϕ: 32;15° (accurately 32°12′)
18	Harran	67; 0	36; 0	problematic; KHU has L/ϕ: 65;0°/36;40°; KHZ has 67;0°/37;0°; this combination of L/ϕ not attested elsewhere
19	Malatya	60; 0	39; 0	KHW has L/ϕ: 61;0°/39;0°; no sources have L: 60;0°
20	Erzerum	66; 0	39; 0	KHW has L/ϕ: 66;0°/39;15°; no other sources have 39;0° (accurately 39°57′); thus minutes of ϕ have been dropped by mistake
21	Sijistan	**9**4; 0	32;20	KHW has L: 74;15° and 94;15°, attesting to the numbers being written out *in words* (7 ⇔ 9 is a common error); ϕ: 32;20° is already in KHZ

				and SUH; ATW has L/ϕ: 87;0°/32;30; Sijistan usually refers to Zaranj; the coordinates for both are confused.
22	Balis	65;15	36; 0	as in KHW
23	Homs	61; 0	33;40	KHW has L/ϕ: 61;0°/34;0°; ϕ is accurately 34°44′; ϕ: 33;40° appears first with KUS
24	Damascus	[60]; 0	33; 0	L: 50:0° (!); KHW has L/ϕ: 60°;0°/33;0°
25	Jerusalem	56; 0	33; 0	KHW has L: 56;0°; PTL has the excellent value 31;40° (accurate value is 31°47′); KHW has ϕ: 32°, sometimes with some minutes; ATW has ϕ: 31;50°, also excellent; ϕ: 33;0° occurs with KHZ and BIR
26	Antioch	61;35	35;10	PTO has already ϕ: 35;30° (accurate value is 36°12′); KHW has L: 61;35° and ϕ: 34;10° and 33;10° (35;10° could be related to the first, if not the second)
27	Ramla	55;40	32; 0	KHU has L: 55;40° but ϕ: 32;40°; ϕ is accurately 31°56′; YUN has ϕ: 32;0°, probably because minutes were missing in KHW
28	Mecca	67; 0	21; 0	as in KHW; note *no* new value of ϕ!
29	Medina	65;20	25; 0	as in KHW
30	Oman	87;30	19;45	KHW has L/ϕ: 84;30°/19;45°, but PTO has L: 87;20° (with ϕ: 19;15°)
31	Kirman	90; 0	30; 0	as in KHW
32	Baghdad	70; 0	**33;25**	L: 70;0° is in KHW tradition (73;0° also attested); note new value of ϕ (KHW has 33;9° or 33;0°), also attested already in SUH, and used in many later sources

Commentary:

The values based on KHW are of less interest than the others. We are here mostly concerned with the very accurate "new" values found in this gazetteer for Isfahan, Shiraz, maybe Rayy, and also Baghdad. In the sequel I shall show that the value for Baghdad, attested in yet earlier sources, predates the values for the three cities in the three most important centres of culture in Buwayhid times. The question arises: who measured the latitudes of Isfahan and Shiraz, and maybe also Rayy, with such remarkable accuracy? It is also of interest that no updated value is given for the latitude of Mecca.

The latitude of Isfahan (no. 15) is given as 32;30° (accurately 32°41′). Earlier values were considerably in error: 34;30° and 34;0° (the latter value also occurs in the gazetteer of Nasṭūlus.

ATW has the much better value 32;40°. The value 32;25° used by various astrolabists from the 12th century onwards is first attested in K&K as occurring in UTT, thereafter also in TUS/ULG.

The latitude of Shiraz (no. 12) is given as 29;36° (accurately 29°38′). Earlier values were seriously in error (32;0° and 31;0°); thus, for example, the gazetteer of Nasṭūlus has 31°. In K&K this value first appears with al-Bīrūnī, and the derivative *Sanjarī Zīj* of al-Khāzin inevitably uses 30;0° (because al-Khāzin derived his values from a map based on al-Bīrūnī's coordinates, so that his values are rounded).[125] The value 29;36°, sometimes rounded to 29;30°, occurs in numerous later sources, including the main TUS/ULG tradition. Curiously, no value is available from ATW.

Then the latitude 33;25° for Baghdad (no. 32) is also excellent. KHW has 33;9° or 33;0°, and al-Khwārizmī used 33° in numerous minor works. The new latitude is attested already in the writings of al-Nayrīzī (*ca*. 900) and in SUH (*ca*. 930),[126] both of which seem to be too early for the Isfahan-Shiraz measurements. This value is used in many later sources.

The coordinates given for Rayy (no. 11) are corrupt (that is, incorrectly engraved), and although I have restored them above, I prefer not to draw any conclusions from them here.

In addition, we note that our gazetteer uses the Khwārizmian coordinates for Mecca (no. 28), apparently in innocence of the better latitude values derived already in the early 9th century.[127]

Finally, we note that only the values for Shiraz and Baghdad had an afterlife of some centuries. That for Isfahan was replaced by 32;25°.

In brief, we are dealing with *an Iranian modification of al-Khwārizmī's geographical data*, incorporating a recently-derived latitude for Baghdad, and "brand new" latitudes for Isfahan and Shiraz, if not also Rayy. This gazetteer surely dates from the eve of the preparation of the more extensive *Kitāb al-Aṭwāl wa-'l-ʿurūḍ*, on which see **VIIc-4c**. One may wonder if this activity had anything to do with the observatory of the Buwayhid Sharaf al-Dawla (reg. 982-989) at Baghdad. Otherwise, apart from the contemporaneous ʿAbd al-Raḥmān al-Ṣūfī and his star observations in Shiraz, I am not aware of any astronomers in Isfahan or Shiraz associated with any latitude observations until the Malikshāh Observatory, which seems to have been based in Isfahan from *ca*. 1075 to *ca*. 1092.[128] This, I believe, brings us back to the enigmatic *Kitāb al-Aṭwāl wa-'l-ʿurūḍ*.

11 An astrolabe by Muḥammad ibn Abi 'l-Qāsim al-Iṣfahānī al-Ṣāliḥānī dated 496 H

International Instrument Checklist #122.
Florence, Museo di Storia della Scienza: 1105. Formerly in the Collection of Prince Corsini.
Earlier provenance?

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[125] King, *Mecca-Centred World-Maps*, pp. 71-75.
[126] King, "Earliest Muslim Geodetic Measurements", pp. 226-227.
[127] *Ibid*., pp. 225-226.
[128] Sayılı, *The Observatory in Islam*, pp. 160-166, especially p. 164 on the location in Isfahan, which seems beyond discussion.

Brass. Diameter: 122 mm. Thickness: 4 mm. Signed and dated.
Bibliography: Gunther, *Astrolabes*, I, p. 263 (no. 122: "Prince Corsini's Moorish Astrolabe"); *Florence MSS 1954 Catalogue*, pp. 61-62 (no. 1105); Mayer, *Islamic Astrolabists*, p. 59. On the star-positions see Stautz, *Mathematisch-astronomische Darstellungen auf mittelalterlichen Instrumenten*, pp. 48 and 50.

This astrolabe is apparently dated 496 H [= 1102/03], or possibly 596 H [= 1199/1200] although there are only two dots on the intitial *tāʾ*, which means 400 rather than 500. The full name of the maker is given as Muḥamad ibn Abi 'l-Qāsim ibn Bakrān al-Najjār al-Iṣfahānī al-Ṣāliḥānī, not otherwise known to me. The epithet al-Najjār indicates "the carpenter" or rather perhaps a more general kind of craftsman,[129] and Ṣāliḥān is a *maḥilla* near Isfahan.[130]

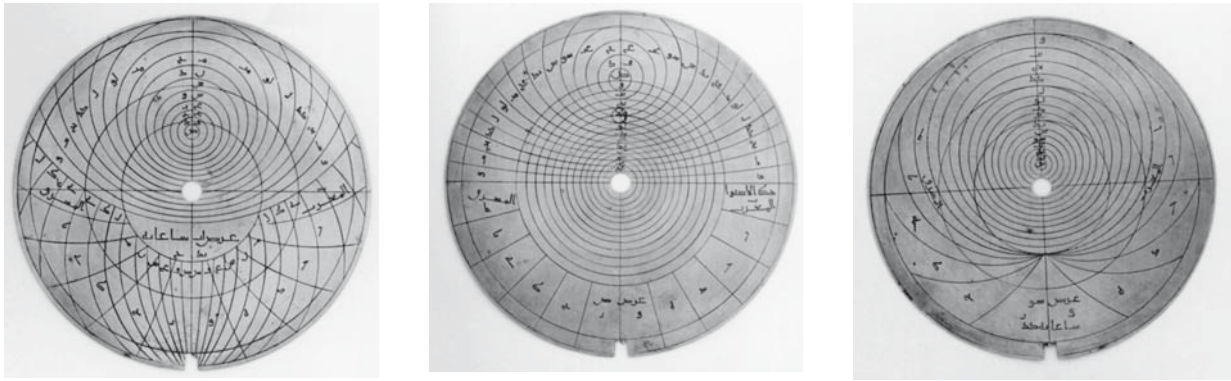
The throne is raised and high and it has three holes and six lobes of different sizes on each side. The shackle has trowel-shaped arms and supports a thick ring; both are original. The scale on the rim is divided 5°/1°-5° (without tens and hundreds), and is rather wide. The mater has a peg at the bottom to hold the plates and is marked with four concentric circles corresponding to the summer solstice, the equinoxes and—roughly—to the inside and outside of the circumferential bar on the rete.

The rete is in the early Abbasid tradition, that is, it bears no trace of influence by al-Khujandī or his imitators, although it should be noted that both legs and both hands of Orion are shown (as is indeed the case on **10** above). It is distinguished by the fact that the long pointers for *fam qayṭus* and *ʿunuq al-shujāʿ* respectively cross and break into the lower circular bar (see also **10**). Also, the extremities of the circumferential frame are attached to the ecliptic by two supports. In all the rete bears markings of the dagger variety for 28 stars, which are as follows:

fam qayṭus		***al-ʿanāq***
al-ghūl		*al-rāmiḥ*
ʿayn al-thawr		*ʿunuq*
al-ʿayyūq		*al-fakka*
al-rijl	A	*qalb al-ʿaqrab*
yad	A	*al-ḥawwāʾ*
al-rijl	B	———————
yad	B	*al-wāqiʿ*
———————		———————
al-yamāniya		*al-ṭāʾir*
———————		*dhanab al-dulfīn*

[129] The term *najjār* seems to mean something other than merely "carpenter". See, for example, Hill, *Pseudo-Archimedes on Water-Clocks*, p. 7, and also **XIVc-0**.
[130] al-Suyūṭī, *al-Lubāb*, p. 160a.

Figs. 11a-b: The front and back of the Muḥammad ibn Abi ʻl-Qāsim al-Iṣfahānī al-Ṣāliḥānī (#122). [Courtesy of the Museo di Storia della Scienza, Florence.]

Fig. 11b

Figs. 11c: The plates for Isfahan (latitude 32°) and for latitudes 0°/90° and 66°.

al-shaʾāmiya
ʿunuq al-shujāʿ
qalb al-asad
janāḥ al-ghurāb
———————————
al-aʿzal

al-ridf
dhanab al-jady
al-mankib
al-khaḍīb
dhanab qayṭus

The positions of the stars are remarkably accurate (Stautz).

The four plates bear altitude circles for each 6° and sometimes azimuth circles for each 10° below the horizon (marked A below) for the following latitudes, those for 0° and 90° (*khaṭṭ al-istiwāʾ* and *ʿarḍ ṣ*) being represented on the two halves of a single plate:

1a	0°		$[12]^{h}$	-	
2a	24		13;31	[0]	
2b	30		13;56	[-2]	see below
3a	31		13;58	[-5!]	see below
4a	32	A	14; 8	[0]	
3a	33		14;13	[0]	
4b	36	A	14;30	[0]	
1b	66		24	-	
1a	90		$[12^{\text{months}}]$	-	

The errors are shown for recomputation with an obliquity of 23;51°. The longest daylight for latitude 31° actually corresponds exactly to latitude 30° with this obliquity. The markings are arranged so that the cuts at the bottom of the plates reach to the circle for the winter solstice, an unusual feature. The additional markings on the plates for latitudes 32° and 36° indicate that the maker had Isfahan and, probably, also Rayy, in mind—see also below. Curious is the omission of a plate for Mecca, when one serving Medina is included.

The back bears two altitude scales divided 5°/1°-5°. In the upper left is a set of horizontal parallels for each 5° up to 85° and radii for each 5°. In the upper right there is a solar quadrant with uniform zodiacal scales arranged axially (signs 3 - 8 vertically and 9 - 10 - 11 - 0 -1 - 2 horizontally in *abjad* notation). There are curves for the solar altitude at the *ẓuhr* and the *ʿaṣr*, both for latitude 32°, serving [Isfahan] and marked *awqāt al-ẓuhr* and *awqāt al-ʾaṣr li-ʿarḍ lb*). In addition there is a curve for the duration of twilight marked *mā bayn al-ṣubḥ min al-mustawiya li-ʿarḍ lb*, "(the time) between daybreak (and sunrise) in equatorial (hours) for latitude 32°". This unusual feature also appears on certain later astrolabes from Iran. There is a single qibla indicator for Isfahan shaped like a *miḥrāb* and marked *qiblat Iṣfahān* at 38° W of S. Note that this value is used in an illustration of a horizontal sundial for Isfahan illustrated in a 13th- or 14th-century manuscript.[131] Below the horizontal diameter is a double shadow square for base 12 on the left and 6;30 on the right with scales divided 3/1-3 and 2/1-2, respectively, and inside the squares are engraved *ẓill al-aṣābiʿ qmd* and *ẓill al-aqdām mb yh*, meaning "shadows in digits 144 [= 12 × 12]" and "shadows in feet 42;15 [= 6;30 × 6;30]". The inscription below the shadow squares reads:

صنعه محمد بن أبي القسم بن بكران النجار الإصفهاني الصالحاني في سنة تصو

"Constructed by (*ṣanaʿahu*) Muḥammad ibn Abi ʻl-Qāsim ibn Bakrān al-Najjār al-Iṣfahānī al-Ṣāliḥānī in the year 496 (Hijra) [= 1102/03]."

See above on the problem of the date.

The alidade is fitted with uniform radial markings from 0 to 60 on one side and non-uniform markings from 0 to 90 corresponding to the Sine on the other. In addition there is a universal sundial with markings for the seasonal hours (see **Fig. XIIa-C1c**).

The vanes are 12 mm high. The pin has a circular button decorated with six spikes emanating from a small circle at the centre, and the wedge is a 20th-century paper-clip (Italian ?).

Later markings

Latin abbreviations for the names of the first two signs—*ARI* and *TA*—are found on the rete.

12 Miscellaneous bits and pieces

12.1 A solitary plate with ogival markings from a "complete" astrolabe

International Instrument Checklist #4021.
Copenhagen, Davids Samling (= The C. L. David Collection): 7/1983. Provenance?
Brass. Diameter: 137 mm.
Unpublished. See Charette, *Mamluk Instrumentation*, p. 64.

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[131] Reproduced in King, *Mecca-Centred World-Maps*, p. 301, with caption on p. 300, and also pp. 104-105. See also **Fig. X-7.1.5**.

This solitary plate—see **Figs. 12.1a-b**—is clearly of 10th- or 11th-century provenance. The engraving bears a suspicious resemblance to that of al-Muḥsin ibn Muḥammad al-Ṭabīb (see **5**)—compare, for example, the letters of the word *ʿarḍ*, "latitude"—but I prefer not to assert that it is due to him. The plate is remarkable in that first, it was intended for an astrolabe with extended radius of projection, and second, the markings are ogival—see Michel, *Traité de l'Astrolabe*, p. 61, and also Charette, *Mamluk Instrumentation*, p. 76, for some yet more complicated markings.

The markings extend beyond the Tropic of Capricorn, thus serving an astrolabe of the *kāmil*, "complete", variety: see already **8.1**. The outer radius corresponds to a declination of *ca*. -36°.[132] There is a very small peg (partly broken?) at the bottom. On one side there are type-A ogival markings for latitude 36° and on the other type-B ogival markings for latitude 42°. Altitude circles are engraved for each 3° of altitude. The lengths of daylight are given as $14;30^h$ [0] and $15;7^h$ [-1], respectively, and these are based on obliquity 23;51°.

This important piece is a unique specimen of a non-standard plate from the early period of Islamic instrumentation. Later examples are known from a few astrolabes of the al-Kirmānī family (see §1.4.12-14 of the Frankfurt catalogue) and from various instruments of the Lahore school.

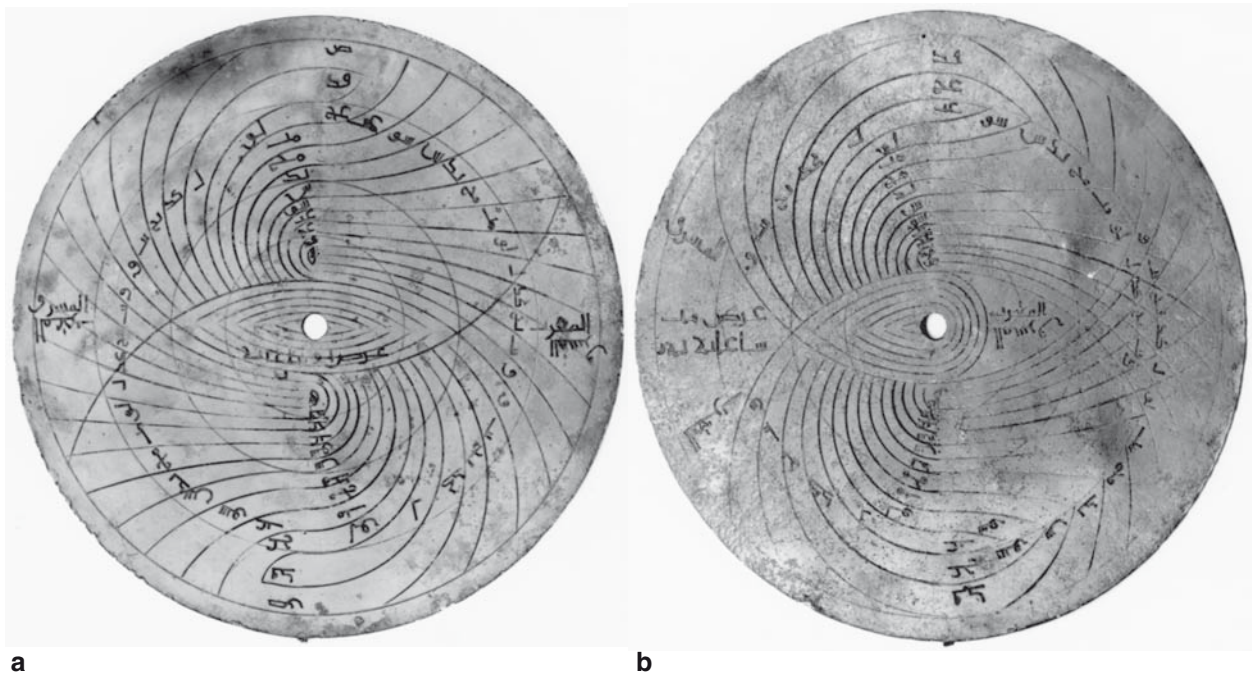
12.2 A solitary plate

International Instrument Checklist #109 = #3549.
New York, Metropolitan Museum of Art: 91.1.535. Acquired in 1891. Provenance?
Brass. Diameter of mater: 15.5 cm.
Bibliography: King, "Yemeni Astrolabe", pp. 105-106, and pls. 6-7 (both sides), and now **XIVa**.

A single plate of Abbasid provenance (see **Figs. 12.2** and **XVI-3.2**) is found inside the astrolabe of the late-13th-century Yemeni Sultan al-Ashraf (see **XIVa**). There are altitude circles for each 6° (and no azimuth circles), and the two sides of the plate serve the 6th and 7th climates with longest day $15^1/_2{}^h$ and 16^h, respectively, the associated latitudes being also given as 41° (*sic*) and 48°. Now in fact the latitude of the 6th climate is closer to 45°, and the latitude underlying the first plate is about this. The latitude of the 7th climate rounds to 48° only for obliquity 24°; for lower values of the obliquity it rounds to 49°. The length of daylight in the 6th climate, $15^1/_2{}^h$, is written in the unusual form: *yh nisf*, literally "15 (and a) half".

Later additions: For some of the seasonal hours the numbers have been repeated in capital Greek letters; they were clearly added by a Byzantine craftsman.

132 See Charette, *Mamluk Instrumentation*, p. 64.

a **b**

Figs. 12.1a-b: The two sides of a solitary plate with non-standard markings from a "complete" (*kāmil*) astrolabe (#4021). [Courtesy of the Davids Samling, Copenhagen.]

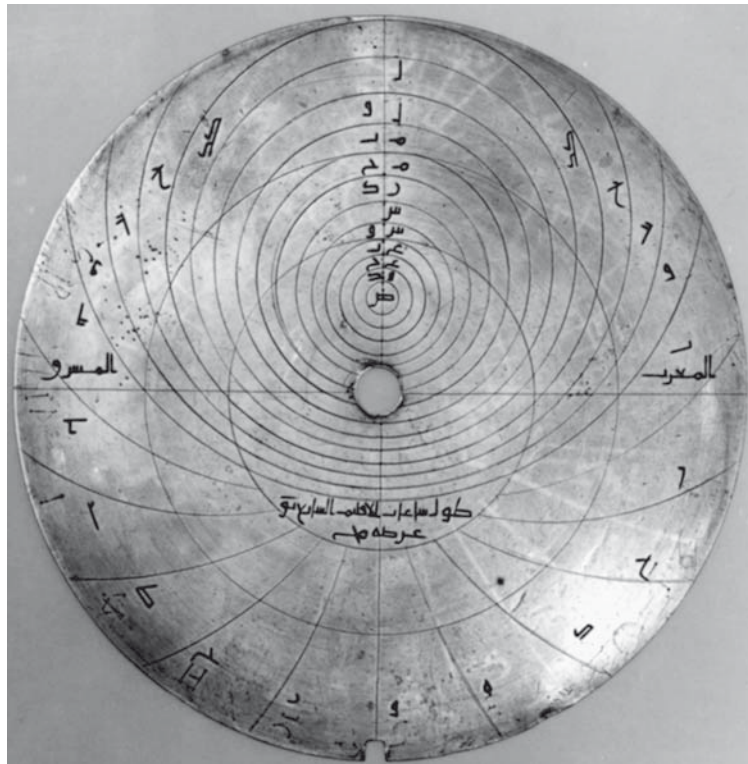



Fig. 12.2: One side of a solitary Abbasid plate for the climates (#109). See **Fig. XVI-3.2** for the other side. [Courtesy of the Metropolitan Museum of Art, New York.]

12.3 A solitary plate

International Instrument Checklist #1026.
Oxford, Museum of the History of Science: 57-84/155. Formerly in the Collection of J. A. Billmeir. Earlier provenance?
Brass. Diameter of associated mater: 112 mm.
Bibliography: [Francis Maddison] in *Oxford MHS Billmeir Supplement Catalogue*, pp. 16-18. The spurious nature of this plate was noticed.

A single spurious plate with *kūfī* inscriptions in the astrolabe of Khafīf (see **1a**) bears altitude circles for each 6° for latitudes:

36°	14;28^{h}	[-2/0]
41	15; 0	[-1/+2]

The underlying obliquity is difficult to pinpoint, the errors shown being for obliquity 23;51° and 23;33°/23;35°, respectively. The cutout is at the top of the plate, that is, at the wrong end of the meridian, so that the plate would only fit upside down in the mater. This does not render it useless, but one wonders what the person who did this thought he was doing. But perhaps this plate was made for another astrolabe. Unlike the other plates in this astrolabe, no inscriptions have been added in Armenian.

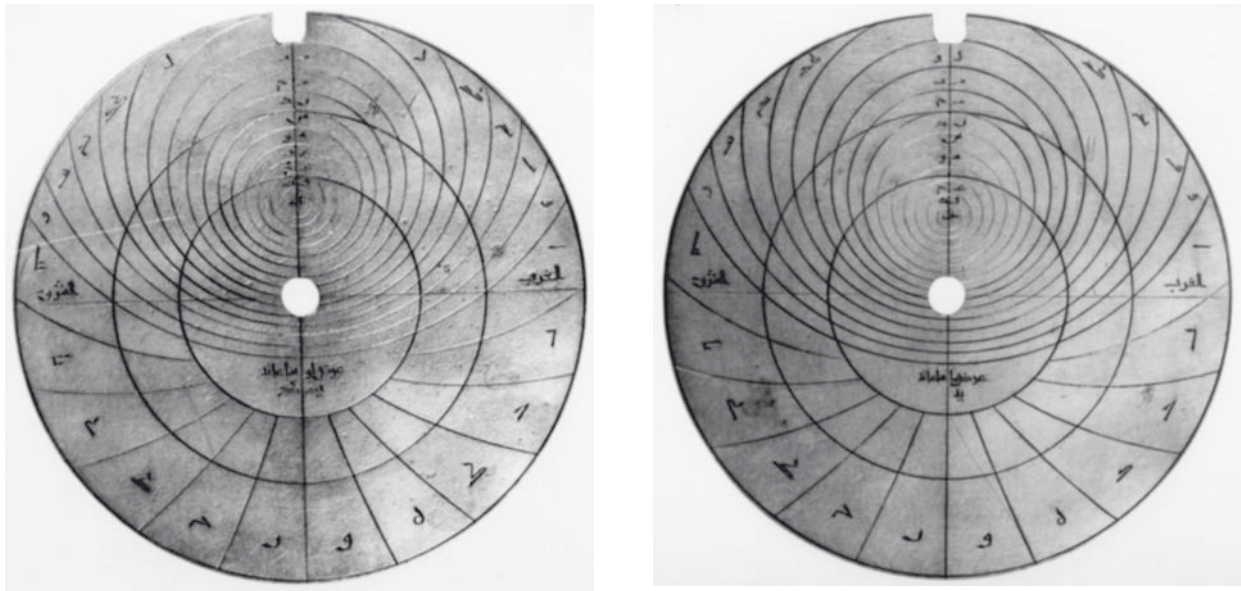



Fig. 12.3: The two sides of a solitary Abbasid plate in the astrolabe of Khafīf (#1026). [Courtesy of Museum of the History of Science, Oxford.]

13 A 13th-century (not 10th-century) horary quadrant for [Nishapur or the 4th climate] by Muḥammad ibn Maḥmūd (al-Ṭabarī)

New York, Metropolitan Museum of Art, inv. no. 36.20.54 (Rogers Fund, 1936). Unearthed during excavations by an MMA team in Nishapur in 1936. Exhibited at the "Festival of Islam in London", 1976.
Brass. Radius of quadrant: 65 mm.
International Instrument Checklist #5001
Unpublished. On the accuracy of the scale and the horary markings see Stautz, *Mathematisch-astronomische Darstellungen auf mittelalterlichen Instrumenten*, pp. 51 and 52.

Whereas the Muslims learned of the astrolabe from their Greek predecessors, the astronomical quadrant was a purely Muslim invention (**X-6**). There are different kinds of quadrants, and the type that concerns us here was developed in Baghdad in the 9th century (see **Fig. XI-4.1a**). As we have seen, such quadrants appear already on some of the more sophisticated 10th-century ʿIrāqī astrolabes (**8.1** and **9**) and they feature occasionally on later pieces (see **Fig. X-6.3.1**). Several varieties are illlustrated by al-Marrākushī and Najm al-Dīn al-Miṣrī.

This piece has been though to date from the 10th century, for it was apparently unearthed in a layer from that century during excavations at Nishapur in 1936. The elegant *kūfī* inscriptions would confirm this. However, Francis Maddison and Emilie Savage-Smith have identified the maker, here named only as Muḥammad ibn Maḥmūd, with the Muḥammad ibn Maḥmūd al-Ṭabarī who made a globe in 684 H [= 1285/86] (#6006+), which is now in the Khalili Collection in London.[133] The maker's signature on the globe is shown in **Fig. 13c**. Thus, we have been spared repeating the mistake of assigning the quadrant to the 10th century, as I did in the article "Rubʿ" in the *Encyclopaedia of Islam*. Another early horary quadrant, possibly also 13th century, and this time for the latitude of Cairo, is described in **A2** below.

The markings on these quadrants are essentially graphical representations of the solar altitude at the seasonal hours as a function of solar longitude, that is, throughout the year. The solar longitude is entered radially, the divisions being uniform and serving a pair of zodiacal signs having the same solar declination (that is, symmetrically placed with respect to the solstices). The radial scales enable the user to insert the solar longitude, the signs of the zodiac being engraved along the two radii, from the innermost circle for the winter solstice, the first major division serving Aquarius and Capricorn, to the outermost circle for the summer solstice, the last division serving Cancer and Gemini. The solar altitude is read from the scale on the circumference. There are curves for each of the six seasonal hours between the time when the sun is on the horizon in the east or west and midday, which is the sixth hour. The seasonal hours are a survival from Antiquity and were in common use in the Islamic Middle Ages.

The front bears a scale divided 5°/1° and labelled for each 5° (without tens). There are problems with the divisions, especially between arguments 75° and 90°. In fact, between 0°

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133 *London Khalili Collection Catalogue*, I, p. 212-213 (no. 123), also King, "Review", col. 255. A poor copy of this globe, complete with a copy of the inscription, is in the Louvre (#6006): see Savage-Smith, *Islamicate Globes*, pp. 220-221 (no. 6), and Mayer, *Islamic Astrolabists*, p. 72.

a

b

c

Figs. 13a-c: (a) The unsigned horary quadrant for latitude 36° (#5001). Compare the only other surviving instrument of this kind, illustrated in **Fig. A2a**. [Courtesy of the Metropolitan Museum of Art (Rogers Fund, 1936), New York City.]

(b) Detail of the signature of Muḥammad ibn Maḥmūd on his quadrant.

(c) The signature of Muḥammad ibn Maḥmūd al-Asṭurlābī, who signs himself elsewhere al-Ṭabarī, on the globe he constructed in the late 13th century. The similarity with the signature on the New York quadrant is remarkable, and adequate for attributing the latter to al-Ṭabarī. [From *London Khalili Collection Catalogue*, I, p. 212.]

and 5° and again between 85° and 90° there are six 1° divisions. The zodiacal scale starts at a point 0.20 of the radius of the horary markings from the centre and is divided equally for six signs: Cancer to Sagittarius on one axis and Capricorn to Gemini on the other. The hour curves are reasonably-smooth sigmoid curves. Burkhard Stautz states that the curves are not very accurate but alas presents no graphics. The underlying latitude is [36°], serving Nishapur and also the fourth climate. The solstitial midday altitudes imply that the obliquity was taken as [24°]. The inscription:

صنعه محمد بن محمود

"Constructed by Muḥammad ibn Maḥmūd"
is engraved on the outer band of quarter-circles for the signs. The circular parts of the *mīm*s give the impression of having been stamped. There are no markings on the back beyond the twoaxila radii and some scratches. The sighting vanes are cylindrical on rectangular protrusions, but there are no viewing holes.

These descriptions were published in 1995 along with my accounts of the two very early astrolabes in Kuwaiti collections, **3.1** and **9**, and I include them here rather than consign them to oblivion.

A1 An astrolabe by Muḥammad ibn Ḥāmid ibn Maḥmūd al-Iṣfahānī dated 571 H

International Instrument Checklist #4199.
Kuwait, Islamic Archaeological Museum (Dār al-Āthār al-Islāmiyya), inv. no. LNS 34M. Purchased from Alain Brieux, Paris, *ca*. 1976. Found in a well in Nishapur in 1973. Exhibited in London in 1976 and loaned to the Institut du Monde Arabe in Paris in the late 1980s.
Brass. Diameter: 89 mm.
Bibliography: *London SM 1976 Exhibition Catalogue*, pp. 111-112 (no. 51) (unpublished); and the following Kuwait catalogues: *NM 1984*, p. 7 and *DAI 1989*, p. 12; King, "Kuwait Astrolabes", pp. 89-91 and 92 (no. 3).

Already in the 10th century, fine astrolabes were being made in Isfahan. In the 12th century, there was a family of astrolabists working there. Four astrolabes signed by Muḥammad ibn Ḥāmid ibn Maḥmūd al-Iṣfahānī are known besides this one, and are now preserved in Istanbul, Tehran and London: see **Fig. X-1.5** for the second. A single astrolabe made by his father Ḥāmid is known, and his brother Masʿūd also bore the epithet *al-asṭurlābī* but none of his instruments has survived.[1] Whilst the *nisba* al-Iṣfahānī is not in itself proof that they worked in Isfahan, markings on the instruments show that they did indeed. The Istanbul and Tehran astrolabes are considerably more ornate than the Kuwait and London pieces (of the last only the mater remains), and the Kuwait piece is more reminiscent of the single surviving astrolabe by the

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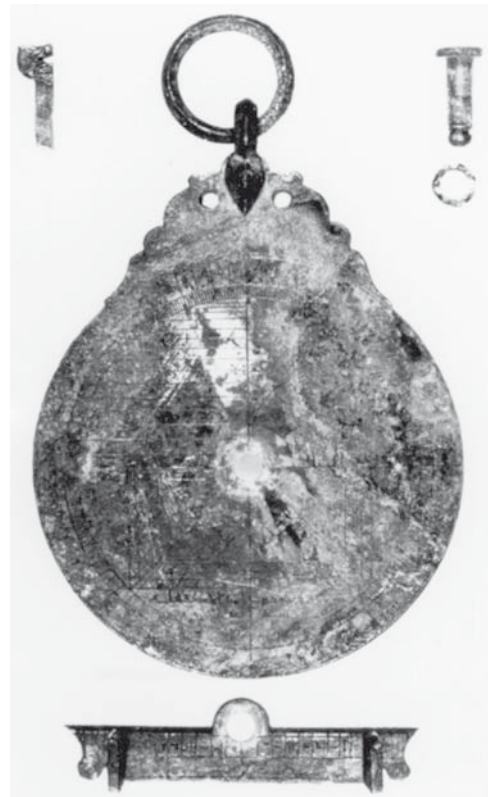
[1] On the family see Mayer, *Islamic Astrolabists*, pp. 46 (father) and 67 (son), and more especially Maddison, "Locks", pp. 148-153.
The astrolabe by Ḥāmid is:
#4: Leonard Linton Collection (acquired from Alain Brieux, Paris, formerly in the Negrotto Collection (?) and then in the S. V. Hoffmann Collection; for some time on loan to the National Museum of American History, Washington, D. C.; exhibited in Washington, D.C., and Riyadh in 1985); diameter 134 mm—see Gunther, *Astrolabes*, p. 117 (no. 4) and pl. XXIV; *Linton Collection Catalogue*, pp. 83 (no. 161), with superb colour plates of the front and back); *Riyadh 1985 Exhibition Catalogue*, pp. 80-81 (with superb colour plate of front); *Washington NMAH Catalogue*, pp. 62-64 (no. 4).
The other astrolabes by Muḥammad are:
#1177: Istanbul, Türk ve İslām Eserleri Müzesi, inv. no. 2952, dated 556 H, diameter 125 mm. See Mayer, *Islamic Astrolabists*, p. 67, no. I and pl. V (back only); Nasr, *Islamic Science*, p. 120, pl. 74, with the false caption (p. 243) "astrolabe from Seville of the 7th / 13th century"; Meyer, "Instrumente", p. 23, pl. 3 (front only).
#1211: Tehran, Museh-e Iran-e Bastan (ex Hakim Collection, London), inv. no. 148, dated 558 H; diameter unknown: see Zick-Nissen, "Astrolabes", p. 183, n. 2, and p. 186 (illustration of the front); Maddison, "Locks", p. 155 and fig. 9 (front and back).
#3532: London, Ahuan Gallery; undated, diameter 125 mm.

a

b

Figs. A1a-b: The front and back of the astrolabe of Muḥammad ibn Ḥāmid ibn Maḥmūd al-Iṣfahānī dated 571 H̱ [= 1175/76] (#4199). [Courtesy of the Dār al-Āthār al-Islāmiyya, Kuwait.]

father. Both pieces are in the tradition of Abbasid astrolabes from the 10th century (exemplified by that of Nasṭūlus—see above), with, however, more elaborate thrones and additional astronomical markings, including quadrants and scales of the kinds developed in Baghdad in the 9th century, on the back.

The throne is large with two holes on each side of a vertical line. There are three lobes of different size and one prominent small one on each side. The suspensory apparatus is original, with trowel-shaped sides to the shackle. The scale on the rim is divided 5°/1°-5°. The rim is damaged in the upper left quadrant. The mater itself is marked only with the three base circles, and there is a peg below the centre at 0.86 of the inner radius to hold the plates in position.

The rete is simple and is in the Abbasid tradition. The equinoctial bar is rectilinear and there

is a handle on the right-hand support of the equatorial bar. The scale of the ecliptic is divided for each 6° and the divisions are not labelled. The star-pointers are dagger-shaped, some with curved indicators, apparently for 14 (= 5 + 3 + 3 + 3) stars (Brieux & Maddison state that there are 15), as follows (the order is not certain in the first quadrant):

[*al-ghūl*] name unclear	___________
al-dabarān	*al-rāmiḥ*
al-ʿayyūq	*fakka*
yad	*al-ḥawwāʾ*
rijl	___________
___________	[*al-wāqiʿ*] name not visible
al-yamāniya	*al-ṭāʾir*
al-shaʾāmiya	[*al*?]-*ridf*
qalb al-asad	

There are two plates with altitude circles for each 6° and either curves for the equinoctial hours since sunset in addition to curves for the seasonal hours (H below) or azimuth curves for each 10° below the horizon (A). The latitudes served are:

1a	30	A	$13;58^{h}$	[0]
1b	32	A	14; 8	[0]
2a	36	H	14;**22**	[?]

The lengths of daylight—at least the first two—are based on obliquity 23;51°. My reading 14;22 may be my mistake for 14;32 [+2] or even 14;30 [0]. But this is not the only problem. In the Kuwait catalogue I wrote that plate 2b had similar markings for latitude 34°, which together with the others would provide a nice range for both Iran and Iraq. Alas, since I do not have a complete set of photos, I cannot check this. Also the London 1976 catalogue omits the latitudes. In the Frankfurt catalogue, however, I find that I wrote that plate 2b is marked with horizons for latitudes between 18° and 38° with lengths of maximum daylight indicated as follows:

38	$14;39^{h}$	[?]

The value $14;39^{h}$ is in error by -3/-1/0′ for obliquity 23;51/35/33°, so it is important to investigate the other values. Somebody should look at this piece again.

The back bears two altitude scales divided 5°/1°-5°. In the upper left quadrant is a sine quadrant (sines only) and in the upper right a zodiacal quadrant displaying the solar altitude at the *ẓuhr* and the *ʿaṣr* for latitude 32°, that is, [Isfahan]. In the lower half are two shadow squares (6;30 *aqdām,* 12 *aṣābiʿ*). The inscription reads:

صنعه محمد بن حامد الإصفهاني سنة ثعا

"Constructed by Muḥammad ibn Ḥāmid al-Iṣfahānī in the year 571 (Hijra) [= 1175/76]."

A2 The horary quadrant for [Cairo] by the muezzin Saʿdū ibn ʿAlī

International Instrument Checklist #5002.
Formerly in the collection of Jasim al-Homaizi, acquired from Alain Brieux in Paris *ca*. 1976. Stolen during the Iraqi occupation of Kuwait and not yet recovered.
Brass. Radius: *ca*. 6 mm. Thickness: 1 mm.
Bibliography: *London SM 1976 Exhibition Catalogue*, p. 151 (no. 71); King, "al-Khwārizmī", esp. p. 30, pl. 10; and *idem*, "Kuwait Astrolabes", pp. 91-93 (no. 4). Maker listed in Mayer, *Islamic Astrolabists*, p. 71, with attribution to 10th century. Briefly described in *London SM 1976 Exhibition Catalogue*, p. 151 (no. 70, dated to 10th or 11th century), but this was never published. Front illustrated in the article "Rubʿ" in EI_2, with dating to 10th century. On the accuracy of the scale and the horary markings, see Stautz, *Mathematisch-astronomische Darstellungen auf mittelalterlichen Instrumenten*, pp. 51 and 52.

Only two early Islamic quadrants survive, both horary quadrants serving to find the time of day from the solar altitude. One, recovered from excavations in Nishapur in 1936 and datable to the 10th century, is discussed above (**13**). The other, treated here, is signed by a muezzin in Fustat or Cairo, and is possibly not much later.[2]

On the right-hand axis are two sights and at the centre is attached a small shackle. The outer scale is divided 5°/1° and labelled 5—10—5—90 from left to right. Inside it is a non-uniform scale divided 5/1-5 up to 25 for shadows to base 7 marked *ẓill al-aqdām*. The zodiacal scale is uniformly spaced and marked for signs Capricorn to Gemini on the left and Sagittarius to Cancer on the right. The circle for the winter solstice is labelled *aqṣar yawm* (shortest day), and that for the equinoxes *khaṭṭ al-iʿtidāl* and that for the summer solstice *aṭwal* for *aṭwal yawm* (longest day). The hour curves have been drawn by connecting points on the zodiacal circles by linear segments. The spaces between the horizon and the midday curve are labelled:

1/12—2/11—3/10—3/9—5/8—6/7

in words. There is dotted curve for the *ʿaṣr* prayer, so marked. To the right of the midday curve is the statement: "seasonal hours (*sāʿāt zamāniyya*) for latitude 30°", and the inscription:

صنعه سعدو بن علي المؤذن

"Constructed by Saʿdū ibn ʿAlī the muezzin."

[2] On the background see King, "Astronomy of the Mamluks", and *idem*, "Muwaqqits", now in **V**. See especially **Fig. XI-9.4c** on some 13th-century illustrations of different kinds of quadrants, alas, none of them horary quadrants for a specific latitude.

Fig. A2a-b: The quadrant of Saʿdū ibn ʿAlī, the muezzin, and a detail of his signature. Compare the only other surviving instrument of this kind, illustrated in **Fig. 13a**. [Courtesy of the owner.]

Part XIIId

A medieval Italian testimonial to an early Islamic tradition of non-standard astrolabes

Dedicated to Mara Miniati in 2003

DEDICATION,
ACKNOWLEDGEMENTS AND NOTES TO THIS VERSION

It is always a pleasure to visit the splendid Istituto e Museo di Storia della Scienza in Florence, and Dr. Mara Miniati was forever ready to help on a variety of matters. Lunches at her favourite *trattoria* were a most pleasant break from instruments. The *Festschrift* published on the occasion of her retirement reflects the appreciation of numerous scholars for her work in the Museum over many years and for her constant readiness to help colleagues.

It is also a pleasure to acknowledge my longstanding debts to the Museum of the History of Science at Oxford and the Museo di Storia della Scienza in Florence. To Dr. François Charette, currently at the Dibner Institute (M.I.T., Cambridge, Mass.), my thanks for his critical comments on earlier versions of this text (and most other new texts of mine) and for most of the graphics. Recent research in Frankfurt on medieval instruments has been generously funded by the German Research Foundation (DFG) in Bonn (see n. 1).

This study first appeared as "A Remarkable Italian Astrolabe from *ca*. 1300—Witness to an Ingenious Islamic Tradition of Non-Standard Astrolabes", in *MUSA MUSAEI: Studies on Scientific Instruments and Collections in Honour of Mara Miniati*, Marco Beretta, Paolo Galluzzi and Carlo Triarico, eds., Florence: Leo S. Olschki, 2003, pp. 29-52. The reader of that article should know that it went through some delivery problems, but—much to the credit of the editors and publishers—finally emerged more or less unscathed. The only remaining problems seem to be the following:

- ❖ Illustrations of the myrtle astrolabes of al-Jazzār and Ibn al-Sarrāj had to be omitted, but these can be consulted in the references provided (notes 18 and 24).
- ❖ P. 37, l. 6: remove "(see Fig. 7)".
- ❖ P. 37, l. 3 of the continuation of n. 17: for "late" substitute "early".
- ❖ P. 46, Fig. 9c: The diagram that ended up here—after much panic and several trans-Atlantic exchanges—is the wrong one: it lacks the curves for "casting the rays", such as are shown here in Fig. 9c.

The present version corresponds more closely to the original version submitted, notably with the use of bibliographical abbreviations. Also, since some of the illustrations submitted with the original text could not be included there, but now are found elsewhere in the present volume, they have been appropriately cross-referenced.

Only in February, 2005, did I realize that a closely-related astrolabe is featured in one of the most famous Flemish painting of the 15th century. Details are included in **2.9**.

TABLE OF CONTENTS

1 Introductory remarks

1 The problem

A charming tiny medieval astrolabe with highly unusual features, preserved for the last century in the Museum of the History of Science at Oxford (**Figs. 1-2**), presents us with a series of challenges with regard to its geographical provenance, historical context, technical function, and authenticity.[1] The instrument has some standard features,[2] but it is those which are non-standard that are of particular historical interest. Lewis Evans acquired the piece for Oxford around 1900 from the bookseller Olschki in Florence. It has not been seriously studied since the early 1930s, when Robert T. Gunther included a description in his *Astrolabes of the World*.[3] Gunther somehow derived 38° for the terrestrial latitude underlying the markings on the mater and hence designated it "Sicilian". The latitude is actually 24°, serving Aswan, *etc*., but the instrument is not to be classified as "Syenian". Nevertheless, there may well be a "Sicilian connection".

The preparation of regional surveys of instrumentation in medieval Europe is a worthwhile and feasible task for the future, but for Italy, the task is somewhat more daunting than for other regions.[4] This is not because of any lack of sources. For over two dozen Italian astrolabes pre-dating 1500 are known but not all published, and also various medieval treatises of Italian provenance on the construction and use of the astrolabe await study. The earliest dated Italian astrolabe (#4523) is signed by one Antonius de Pacent in Lanzano in the year 1420.[5] Some undated pieces, alas also unsigned so that none of them can be conclusively associated with

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[1] This study came into being during the course of the Frankfurt-based project to catalogue all medieval Islamic and European instruments to *ca*. 1500. On some of the results of this see King, "Astronomical Instruments between East and West", and also *idem*, *Ciphers of the Monks*, pp. 364-405. A list of such instruments ordered by provenance and date is available on the website "Catalogue of Medieval Instruments" – see now **XVIII** for the early Islamic instruments.

[2] For general introductions to the astrolabe see *Greenwich Astrolabe Booklet*; North, "The Astrolabe"; Trento, *L'astrolabio*; and now **XIIIa**.

[3] Gunther, *Astrolabes*, II, pp. 319-320 (no. 169); Price *et al*., *Astrolabe Checklist*, #169. My first reflections on this instrument are recorded in King, "Medieval Instruments and their Secrets", pp. 50-52, and *idem*, "Astronomical Instruments between East and West", pp. 168-169. An anonymous description in the website "*Oxford MHS Database*", accessible under "Sicily", gives the date as "*ca*. 1460?" and leads also to another instrument which is not Sicilian at all. The more recent website "*EPACT—Scientific Instruments of Medieval and Renaissance Europ*e" has a fine colour illustration of the front, as well as a description by Jim Bennett partly based on Gunther. The instrument, which now bears the inventory number 40829 in the Oxford collection, here becomes "later 15th century" and "Italian?", but with the latitude still 38°.

[4] The problems of instrumentation in medieval Italy are well reflected by the fact that Gunther in 1932 could provide no introduction to his section on Italian astrolabes, and included in that section some astrolabes that are actually German and French. Major steps to improve the documentation of Italian astrolabes were taken by Tullio Tomba in a series of articles on individual instruments (listed as Tomba, "Astrolabi", A-D) and catalogues of collections in Milan. No list of medieval Italian astrolabes is available, and for the time being the reader may consult the table of contents of "Catalogue of Medieval Instruments", §6.1-5 and §6.7.

[5] This piece, preserved in a private collection in Germany, is analysed in detail in Stautz, "Astrolab aus dem Jahr 1420"; see also *idem*, *Mathematisch-astronomische Darstellungen auf mittelalterlichen Instrumenten*, pp. 88-92 and 249-252. It is not without its problems—the star-positions on the rete are a disaster because the ecliptic and equatorial coordinate systems have been confused, and plates are labelled for different latitudes but all are in fact engraved for latitude 45°—but these do not detract from its historical interest.

Figs. 1-2: The front and back of the enigmatic Oxford astrolabe (#169). [Courtesy of the Museum of the History of Science, Oxford.]

Italy, may well be earlier than this. One of these, #493, preserved in Florence, is possibly the oldest: see further **2.2** below. Of the others, I mention here only the following: one in Oxford (#166),[6] three in Nuremberg (#558, #547 and #548),[7] one in Munich (#621),[8] and two others in private collections (#4509 and #4556).[9]

Clearly, we are dealing with one of the earliest surviving Italian astrolabes, and, also, with the smallest surviving European astrolabe. However, as we shall see, this instrument is important for other reasons, and is surely one of the most interesting astrolabes from the European Middle Ages. Before we can even begin to understand it and to consider its authenticity,[10] we need to survey the possibilities relating to its historical context, first introducing some general concepts. We also need to be aware that astronomical instrumentation in medieval Europe was largely indebted to Islamic instrumentation.[11] Indeed, for most technical innovations in European instrumentation up to *ca*. 1600 we can identify Islamic precedents, although this does not, of course, always imply direct transmission or exclude independent initiative.[12]

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[6] On #166 (Museum of the History of Science, inv. no. IC 166) see Gunther, *Astrolabes*, II, pp. 316-317 (no. 166), and Stautz, *Mathematisch-astronomische Darstellungen auf mittelalterlichen Instrumenten*, pp. 85 and 244. On this piece, purchased in 1899 in Venice, the latitudes serve the climates and there are no clearly Italian features, but I am inclined to think that it is Italian not least because the rete-design bears no relation to the Western Islamic / Iberian tradition.

[7] On #558 (Germanisches Nationalmuseum, inv. no. WI 282), an early medieval European astrolabe of uncertain provenance but possibly Italian, with plates for latitudes between 16° and 52°, see King, "Nuremberg Astrolabes", II, pp. 574-576 (no. 1.72).

On #547 (inv. no. WI 21), a 14th-century Italian quatrefoil astrolabe, with a single plate for 42° and 45°, see *ibid*., II, pp. 576-578 (no. 1.73).

On #548 (inv. no. WI 6), a 14th-century Italian (?) astrolabe with plates for latitudes between 30° and 55° and additional 15th-century markings, probably added in Paris, see *ibid*., II, pp. 578-581 (no. 1.74).

[8] On #621 (Deutsches Museum, inv. no. 5178) see *Munich Astrolabe Catalogue*, pp. 161-176 (no. 2), also illustrated in King, "The Oldest European Astrolabe", fig. 13. This is a composite piece with a very early limbus, rete and plates, and a back from another astrolabe with inscriptions in Hebrew.

[9] On #4509, which has a replacement plate from a Byzantine astrolabe and additional markings in Hebrew, see *Sotheby's 18.6.1986 Catalogue*, pp. 24-25 (lot no. 125); and *Amsterdam NK 1990 Exhibition Catalogue*, p. 101 (no. 186, dated *ca*. 1300, described as French) with a colour plate of the front on p. 106; also King, *Ciphers of the Monks*, pp. 290-291.

On #4556 see the detailed description in *Christie's 29.9.1994 Catalogue*, pp. 34-39 (lot 136), for the provenance, "both Italy and England are contenders" (!)); the front is illustrated in King, "The Oldest European Astrolabe", fig. 21. See now **XIIa-10.2**.

[10] There is an unfortunate trend in our field motivated by the belief that if a historical instrument cannot be understood in the light of our present knowledge, it *must* be a fake. See n. 26 and **2.7** below.

[11] The best overview of medieval European instruments remains Poulle, *Instruments astronomiques du Moyen Âge*, published over 30 years ago. See also King, *Ciphers of the Monks*, pp. 369-419, for some of the latest research. For an overview of Islamic instrumentation see **X**, and for remarks on Islamic and medieval European astrolabes see **XIIIa**.

[12] The same holds for other scientific disciplines. To the list in Ragep, "Freeing Astronomy from Philosophy", p. 51, add astronomical timekeeping and astronomical instrumentation.
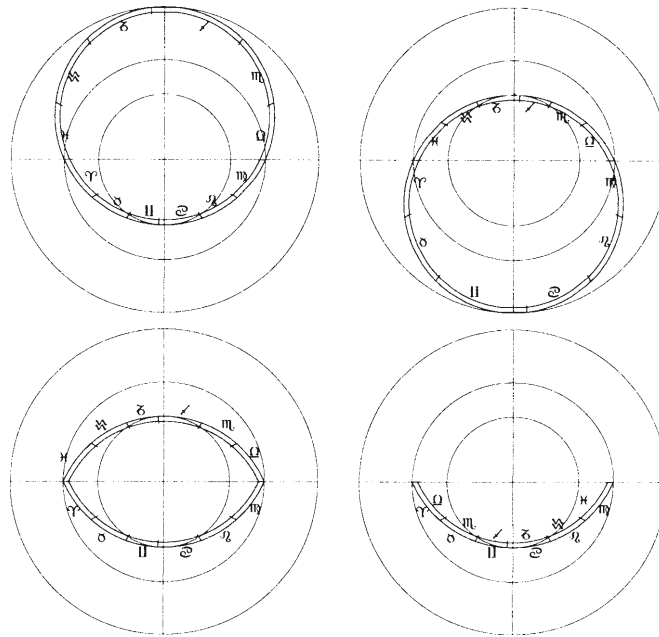
Fig. 3: (a) The standard northern projection of the ecliptic. (b) The standard southern projection. (c) The full myrtle ecliptic, combining the northern projection of the northern signs and the southern projection of the southern signs. (d) The rotated half myrtle ecliptic, on which both halves of the ecliptic are represented on the same single circular arc. This is achieved by rotating the upper half so that it coincides with the lower half. [Graphics by François Charette.]
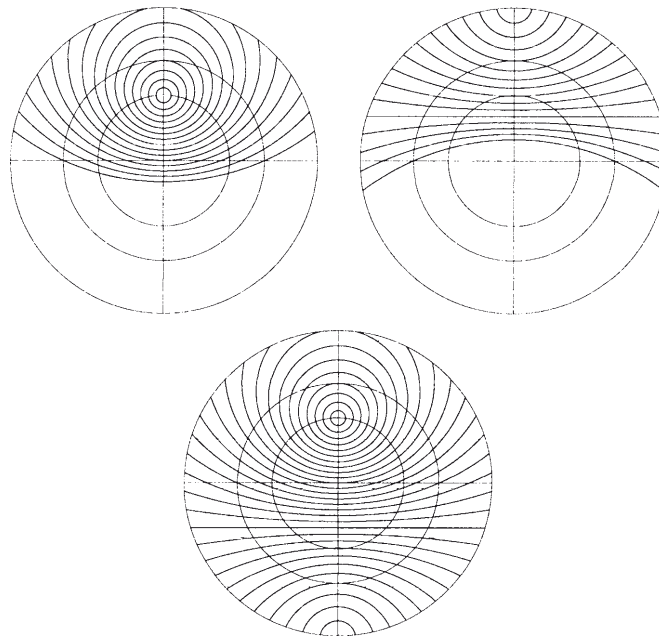
Fig. 4: (a) A set of standard astrolabic markings, that is, based on a northern projection, for latitude 24°. (b) A set of markings for the same latitude based on a southern projection. (c) The combination of such markings, which could be equally be considered as representing altitude circles above and below the horizon for either projection. On the myrtle astrolabe, the markings bounded by the equatorial circle would suffice. See further **Fig. 9**. [Graphics by François Charette.]

Fig. 5: Illustrations of the myrtle and drum astrolabe retes and the full plate of altitude circles that serves them both, taken from a fine copy of the treatise on astrolabe construction by al-Bīrūnī (*fl*. Central Asia, *ca*. 1025). al-Bīrūnī took most of his information on non-standard astrolabes from his early contemporary al-Sijzī, who in his treatise on astrolabe construction, rediscovered in Istanbul in the 1970s, had mentioned not only the different varieties but also the names of those who invented them and a few examples that had been presented to various dignitaries. One particular myrtle astrolabe made by al-Sijzī himself is mentioned on this page. [From MS Istanbul Topkapı Ahmet III 3505, courtesy of the Topkapı Sarayı Kütüphanesi.]

2 Universal and latitude-dependent instruments in medieval astronomy

In the history of spherical astronomy, we can distinguish between solutions that are universal and those that are restricted to a single latitude. The underlying formulae are of course by their nature universal, and the universal solutions to which I refer can be in the form of astronomical tables or astronomical instruments. Already in Greek astronomy, certain solutions were proposed for each of the seven geographical "climates" of Antiquity (see **Fig. XVI-2.1**).[13] These included, for example, tables of oblique ascensions for each of the climates, and astrolabes fitted with plates for each climate. This explains why medieval European astrolabes were sometimes fitted with a set of plates for an extensive range of latitudes, say, 16°-52°. Likewise, an armillary sphere that can be adjusted for any latitude is universal. On the other hand, an astrolabic quadrant derived from a single astrolabic plate serves only a specific latitude. Universal solutions were very popular in Islamic astronomy (see **VIa-b**).

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[13] On the climates in instrumentation, see King, "Geography of Astrolabes", pp. 6-9; *idem*, *Mecca-Centred World-Maps*, pp. 24, 27-28 and 230-234; *idem*, *The Ciphers of the Monks*, pp. 356-357, 360-361 and 411-415; and now **XVI-2-3**.

By a quirk of fate, the latitudes of the climates correspond more or less to localities where serious astronomy was practiced at some time between Antiquity and the European Renaissance: C1: Yemen; C2: Aswan; C3: Alexandria, Cairo; C4: Rhodes, Rayy; C5: Constantinople, Barcelona; C6: Lyon, Po Valley; C7: Vienna, Nuremberg, Paris.

Fig. 6: A unique example of an astrolabe with a "myrtle"-shaped rete made in the Maghrib by ʿAlī ibn Ibrāhīm al-Jazzār in 728 H [= 1327/28] (#3579). There is only one plate, a universal one. An interesting question is whether this particular instrument is representative of the Andalusi tradition of ʿAlī ibn Khalaf and Ibn al-Zarqālluh or the Eastern Islamic tradition described by al-Sijzī, al-Bīrūnī and al-Marrākushī (see **Fig. 5**). [Courtesy of the Museum of the History of Science, Oxford.]

3 Mixed north-south astrolabe projections

The standard astrolabe is based on what is traditionally called a northern stereographic projection, that is, a projection of the *northern* sky in the plane of the celestial equator with the *south* celestial pole as the pole of the projection. The resulting projection of the ecliptic is unhappy, because the northern signs of the ecliptic end up on a small arc and the southern signs on an arc about twice the size (see **Fig. 3a**). On a southern projection, the situation is reversed (see **Fig. 3b**). Muslim astronomers in the 9th and 10th centuries addressed this problem and devised a series of solutions involving combinations of northern and southern projections. With a mixed rete, one must have appropriate combinations of north-south markings on the plate. It helps to keep in mind that in the case of problems involving solar longitude and solar altitude, the same problems can be solved using the opposite solar longitude on the ecliptic and the same solar altitude now *below* the horizon. To put it another way, if one has a mixed ecliptic, one needs a mixed plate with altitude markings below the horizon equivalent to markings above the horizon in the opposite projection (see **Fig. 4a-c**).

The most useful, and at the same time the most aesthetically pleasing of these solutions was the so-called "myrtle-leaf" ecliptic, comprising a northern projection of the northern signs and

a southern projection of the southern signs and bounded by the equinoctial circle (see **Fig. 3c**).[14] With such an ecliptic, one needs only a complete set of altitude circles above and below the horizon to solve all of the standard problems of spherical astronomy. (There is no longer empty space for the markings for the seasonal hours below the horizon, but these can be included nevertheless.) The "drum-shaped" ecliptic was the made up of the two longer arcs of the ecliptic.

With such a combination, one has, however, lost the function of the astrolabe as an "analogue computer" in the sense of a model of the universe, and produced more of an abstract instrument, or less of a representational one. The fact that the myrtle ecliptic is symmetrical about the horizontal (equinoctial) axis was not lost on medieval astronomers: one-half would actually suffice to represent the entire ecliptic—see **Fig. 3d**—with a consequent further loss of "direct" representation of the heavens.

The astrolabe with a myrtle rete was the invention of some unidentified 9th- or early-10th-century Muslim astronomer in Baghdad, for both it and the astrolabe with the drum-shaped ecliptic are mentioned by the mathematician Ibrāhīm ibn Sinān (907-946):[15]

> "Some people make the astrolabe with respect to the northern celestial pole, and this is the most common case. But a minority make it with respect to the southern pole ... . Other people are less conventional: they make the astrolabe in two halves. One of them is (projected) from the northern pole, and the other from the southern pole. ... . [The author then presents illustrations of the myrtle and drum ecliptics.]

The myrtle rete was known to the major Muslim authors of instrument texts thereafter: al-Sijzī in the late 10th century, al-Bīrūnī in the early 11th (see **Fig. 5**), al-Marrākushī in the late 13th, and Najm al-Dīn al-Miṣrī in the early 14th.[16]

Alas, very few Islamic instruments featuring these non-standard features survive. One, preserved in Oxford (#3579), was made in the year 728 H [= 1327/28] by ʿAlī ibn Ibrāhīm al-Jazzār, a muezzin in Taza (now in Morocco) (see **Fig. 6**).[17] It has a full myrtle ecliptic and a universal plate of the type similar to, but not identical with, the one designed by the Andalusī Ibn Bāṣo in the early 13th century (see **Fig. X-5.2.6**). Evidence of other instruments in this tradition is not lacking, but they were clearly not widespread. On the other hand, they were

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[14] I maintain the English equivalent of the Arabic *ās*, "myrtle", as in *al-asṭurlāb al-āsī*, literally "the myrtle astrolabe", meaning "the astrolabe with an ecliptic shaped like a myrtle-leaf on its rete". The reader should consult the works cited in the next note to learn about "buffalo", "crab", "tortoise" and "fish" astrolabes, to name just a few.

[15] Charette, *Mamluk Instrumentation*, pp. 68-69.

[16] See Sédillot-*fils*, *Traité* (on al-Marrākushī, late-13th-century Cairo), pp. 181-182; and Charette, *Mamluk Instrumentation*, pp. 63-83 (general survey and details of the instruments by Najm al-Dīn al-Miṣrī (Cairo, *ca.* 1325)); also Frank, *Zur Geschichte des Astrolabs*, pp. 9-18; Lorch, "Mischastrolabien"; and King, *Mecca-Centred World-Maps*, pp. 345-349. Richard Lorch has prepared a study of the writings of al-Sijzī, which is not yet published. For an overview see also Michel, *Traité de l'astrolabe*, pp. 69-71, although Michel erred when he dismissed these mixed retes as "une coquetterie géométrique".

[17] On the maker, see Mayer, *Islamic Astrolabists*, supp., p. 294. On the universal plate of Ibn Bāṣo and its afterlife in Europe see Calvo, *Ibn Bāṣo and his Universal Plate*, "Ibn Bāṣo's Universal Plate", and "The Use of Ibn Bāṣo's Universal Plate", and also King, "Astronomical Instruments between East and West", p. 156. See now **X-5.2**.

well enough known to have been part of the corpus of Islamic astronomical notions transmitted to medieval Europe, if only to languish there, first being truly appreciated in the Renaissance.[18]

In this connection we should mention a 14th-century Northern French astrolabe, preserved in the Science Museum in London (see **Figs. X-5.4.3** and **6.3.2**), which is unique amongst European astrolabes not only because it has a gear mechanism for representing the relative motions of the sun and moon, but also because it is based on a southern stereographic projection.[19] This piece is clearly of great historical interest not least because the first monumental astrolabic clocks in Europe featured the same.[20] But we perhaps need to be reminded that some astrolabists in 9th- or 10th-century Iraq also made astrolabes based on a southern projection.[21]

4 Mixed north-south ecliptic scales on universal astrolabes

The 11th-century Andalusī astronomer Ibn al-Zarqālluh devised a single plate—based on a stereographic projection from the equinox onto the solstitial colure—which could be used universally since it was independent of latitude. From the same milieu came the universal astrolabe, associated with ʿAlī ibn Khalaf, in which at least a semicircle of such universal markings can rotate over another complete set: this serves the transformation of coordinates from one system—equatorial, ecliptic or horizon-based—to another.[22] The ecliptic would be represented on a diameter and the stars based on a universal projection. However, in order to add to the universal astrolabe some of the functionality of the standard astrolabe, later astronomers devised other representations of the stars and ecliptic on the rete of the universal astrolabe that would fit on the other one-half of the rete. The "half myrtle ecliptic", that is, a half myrtle ecliptic with a double scale, so the northern and southern signs are represented on the same circular arc, was the optimal solution, and now the stars could be in either a northern or southern projection. Their positions in some cases will no longer correspond to the appropriate signs of the ecliptic scale.

Only two Islamic universal astrolabes have survived. One, already known to Gunther, was made in the year 729 H [= 1328/29] by the astronomer Ibn al-Sarrāj of Aleppo (#140): it is universal in five different ways and easily qualifies, from a mathematical point of view, as the most sophisticated astrolabe ever made (see **XIVb-5.1**).[23] The other (#4201) was discovered

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[18] See n. 12.

[19] On #198 (Science Museum, inv. no. 1880.32) see Gunther, *Astrolabes*, II, p. 347 (no. 198) and pl. LXXXI; North, "*Opus quarundam rotarum mirabilium*", pp. 369-371 (pp. 167-169 of the reprint); and King, *Ciphers of the Monks*, pp. 398-399, 402-403, 406, 410, 416-417, also p. 138, n. 6. This piece is not without its problems: for example, the ecliptic on the rete is improperly constructed (see Stautz, *Mathematisch-astronomische Darstellungen auf mittelalterlichen Instrumenten*, pp. 103-104 and 262), as are the scales of the shadow square on the back (see King, *Ciphers of the Monks*, pp. 416-417).

[20] North, "Monasticism and the First Mechanical Clocks", pp. 391-392 (pp. 181-182 of the reprint).

[21] See the text to n. 15 above.

[22] Charette, *Mamluk Instrumentation*, pp. 103-108, provides new sources and new insights to both supplement and correct the discussions in King, "Universal Astrolabe" (1979); and the article "Shakkāziyya" in EI_2, which cites the voluminous publications of the Barcelona school.

[23] On #140 (Gunther, *Astrolabes*, I, pp. 284-285, no. 140) see now **XIVb-5.1**. A detailed study has been prepared: see Charette & King, *Universal Astrolabe of Ibn al-Sarrāj* (forthcoming)

only in the late 1990s: it is from 17th-century Lahore, but is of the kind known from the treatise by ʿAlī ibn Khalaf in its Castilian manifestation, though fitted with a rotated half myrtle ecliptic.[24] This is not surprising, since it is a copy of a simpler instrument also made by Ibn al-Sarrāj.

Suffice it to say at this stage that not a single *medieval* European universal astrolabe has survived. Half-myrtle representations of the ecliptic were known in Europe, namely, on universal plates described by Jean de Linières (*ca*. 1325) and Regiomontanus (*ca*. 1455).[25] We cannot doubt that such instruments, even universal astrolabes, were made in medieval times, but the earliest examples are from 16th-century England and Flanders.[26]

More or less out of the blue, we find John Blagrave of Reading in 1585 proposing a universal astrolabe that in its essence closely resembles a simple version proposed by Ibn al-Sarrāj, with a full myrtle ecliptic, the upper part superposed on the semicircle of universal markings, as well as a calendrical scale around the front of the limbus.[27] The universal astrolabe of Charles Whitwell (*ca*. 1597) preserved in Florence is in this style,[28] as is the unsigned piece preserved in Chicago.[29] A full myrtle ecliptic is found on a "nautical hemisphere" made by Whitwell *ca*. 1597, and on a quadrant made by William Senior in 1600.[30] A half myrtle ecliptic rotating over a universal projection features on an astrolabe made by Adrian Zeelst in Louvain *ca*. 1600.[31] Recently we have discovered a more complicated instrument by an unidentified Spanish instrument-maker working in the Louvain tradition possibly in El Escorial *ca*. 1560; the source of the technical inspiration behind this piece has not yet been established.[32] Suffice it to say,

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[24] On #4201 see *Christie's 4.10.1995 Catalogue*, pp. 20-21 (lot 61), for the rete, and *Christie's 5.4.2001 Catalogue*, pp. 43-45 (lot 32), for the mater. The two parts are now in the hands of the same dealer in London: see now **XIVg**.

[25] See Poulle, "*Saphea*", pp. 508-509, respectively. On the *saphea* see also Zinner, *Deutsche und niederländische astronomische Instrumente*, pp. 145-149.

[26] Only around 1450 do instruments appear in Italy and Germany (Vienna) that could be labelled "Renaissance" as opposed to "medieval".

Also the earliest Renaissance Italian astrolabes present some problems of their own. The earliest one, dated Urbino, 1462, has been stolen: see n. 37. The authenticity of the most spectacular Renaissance Italian astrolabe (#171), associated with Piervincenzo Danti de' Rinaldi *ca*. 1490 (Gunther, *Astrolabes*, no. 171), which is preserved in Hamburg, has been questioned. On this piece, which has the double burden of being partially gilt and having passed through the highly dubious Frédéric Spitzer collection in the late 19th century, see the diplomatic description by Francis Maddison in *Washington 1992 Exhibition Catalogue*, pp. 224-225 (no. 123), and also Levi-Donati, "Astrolabio perugino". The situation is not facilitated by the fact that there is a "real" late-19th-century copy of that very astrolabe in Chicago: see *Chicago AP Catalogue*, pp. 114-116 (no. 28). Also, the earliest Renaissance astrolabe from the Vienna school, dedicated by Regiomontanus to his patron Bessarion in 1462 (#640), was labelled suspect after it had come up for auction at Christie's in 1989. It was returned to Christie's and eventually passed to a private collection, after research had established that it is one of several fine instruments that had not been previously identified, all of which stem from the same workshop or group of workshops: see King & Turner, "Regiomontanus' Astrolabe".

[27] Gunther, *Astrolabes*, II, pp. 492-500 (no. 308).

[28] Turner, *Elizabethan Instruments*, pp. 187-190 (no. 43).

[29] Gunther, *op. cit*., II, p. 501 (no. 309) and pl. CXLI, and Turner, *op. cit*., pp. 86-89.

[30] *Ibid*., pp. 196-198 (no. 47) and 249-250 (no. 77).

[31] Van Cleempoel, *Louvain Astrolabes*, pp. 218-221 (no. 74), also colour plates on pp. 264-265.

[32] Moreno *et al*., "Spanish Astrolabe". Both Julio Samsó and François Charette have registered other interpretations of the underlying Toledan materials.

the fate and fortunes of the universal astrolabe in Europe have yet to be properly documented.

With this background in the climates and notions of universality in instrumentation, mixed north-south projections and unusual types of astrolabes, as well as myrtle retes on universal astrolabes, we now turn to a very remarkable artefact.

2 The Oxford astrolabe

2.1 Basic description

Our astrolabe[33] is a mere 5.9 cm in diameter, and 0.8 cm thick, thus qualifying as the smallest surviving European astrolabe.[34] It barely needs saying that any astrolabe of this size has no serious practical use.[35] The engraving is carefully executed in a bold hand, which appears to be Italian and looks as though it can be dated *ca*. 1300—see further **2.2** below. Or maybe the instrument is a 19th-century Italian copy—see **2.7**.

The throne is of a simple tri-lobe design—three-quarters of a quatrefoil—such as is found on various very early European instruments.[36] The outer scales on the front and back are divided and labelled for each 10° and subdivided for each 2°. The rete bears a complete circumferential ring and two complete horizontal and vertical diameters, the latter extended outwards at the top to serve as a marker on the outer scale. On the ecliptic, whose scale is improperly divided, and the four unlabelled star-pointers see **2.3-4**. The mater bears unusual astrolabic markings for a specific latitude—see **2.5**. The markings and alidade on the back are standard, but merit comment—see **2.6**. The rete and the alidade are riveted in place by an unusual bolt with an eight-pointed star on the front; the rete can rotate freely but could not be removed without breaking the bolt. Some details are shown in **Figs. 8a-c**.

2.2 The engraving

The engraving, which is bold and heavy, but not inelegant, is of a kind not attested on any other astrolabe known to me. It bears some resemblance to that on another, possibly contemporaneous Italian astrolabe (#493) preserved in the Museo di Storia della Scienza in Florence: see **Figs. 7** and **XIIIa-10.4a**. I have recently studied this other piece in detail, as part of an investigation of a series of astrolabes connected with Urbino.[37]

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[33] On previous publications featuring this piece, see n. 3.

[34] A decorative astrolabe from 17th-century Isfahan has diameter 4.1 cm!

[35] See Price *et al*., *Astrolabe Checklist*, pp. 69-84, for the sizes of many surviving astrolabes.

[36] King, "The Oldest European Astrolabe", p. 365, where this piece is mentioned.

[37] The Florence astrolabe, in gilded brass, is of a type that provided the original inspiration for a Renaissance astrolabe (#4506), dated Urbino, 1462, which was stolen from a museum in Moulins (Allier, France) in 1977. This Renaissance astrolabe was of a type that in turn inspired the astrolabe depicted in the intarsia of the *studiolo* of Archduke Federico of Urbino, completed *ca*. 1476. The Florence astrolabe shows signs of having been influenced by the tradition of the prolific Abū Bakr ibn Yūsuf of Marrakesh *ca*. 1200. For detailed descriptions of all of these, see King, "Urbino Astrolabe", and for illustrations also **Figs. XIIIa-10.4a-c**. On the star-positions see Stautz, *Mathematisch-astronomische Darstellungen auf mittelalterlichen Instrumenten*, pp. 115-116 and 279-280.

Fig. 7: The back of the medieval Italian astrolabe in Florence (#493). For the front see **Fig. XIIIa-10.4a**. [Photo by Franca Principe, courtesy of the Museo di Storia della Scienza.]

The numerals on the Oxford piece are a curious mix (and different from those on the Florence piece). For '1' we find a capital 'I'. The forms for '4', '5', and '7' are old-style "Gothic", whereas the forms for '2', '3', '6', '8' and '9' are more developed and well rounded.[38]

My dating of both the Oxford and the Florence astrolabes to *ca*. 1300 is based on a feeling that they are not 15th century, nor are they 14th century. Only a comparison of the engraving with that on *dated* Italian metalwork from these periods, which I have not pursued, or the (unlikely) rediscovery of a related instrument that is dated, could confirm or disprove my tentative dating.[39]

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[38] The examples of Hindu-Arabic numerals from Italy recorded in Hill, *Arabic Numerals in Europe*, pp. 108-121, are mainly too late to be of any use here. For a new look at the Hindu-Arabic numerals in medieval Europe, see King, *Ciphers of the Monks*, pp. 309-317.

[39] In 1956 the French expert on historical instruments Marcel Destombes claimed that an astrolabe that he had stumbled across was from 10th-century Catalonia. His detractors maintained that the piece was at the earliest of 12th, 13th, 14th, 15th century provenance, if not a 20th-century fake. Comparison with several dozen other early astrolabes reveals that the piece could *only* be from the 10th century, although the names of the signs on the rete may be two or three centuries later: see King, "The Oldest European Astrolabe". Also the unusual engraving is attested elsewhere *only* in 10th-century Catalonian inscriptions: see Mundó, "Analyse paléographique".

There has been a tendency to date medieval European instruments too late. For example: the well-known 15th-century French miniature of the monk Henricus Suso with a series of astronomical instruments includes an astrolabe that I would have said was 14th-century French. However, a manuscript copied in Paris in 1276-77 contains an illustration of an astrolabe with the same rete-design. See further King, *Ciphers of the Monks*, pp. 42, 393 and 397.

2.3 The ecliptic on the rete

The ecliptic is of the rotated half myrtle variety (see **Fig. 3d**) with double graduation, so that the northern projection of the northern ecliptic and the southern projection of the southern ecliptic are represented as a single minor arc of a circle. The corresponding rete and plate beneath are restricted to the domain within the celestial equator.

The two halves of the ecliptic are superposed in such a way that both the northern and the southern signs run counter-clockwise from the left-hand side. The arrangement of the two half sets of signs is to some extent arbitrary, and has no consequences for operations with the sun. For operations with the stars we are confronted by the fact that the stars do not correspond to the appropriate signs of the ecliptic scale. One could live and work with this—with some stretching of the imagination and an occasional *saltus stellae*—if the stars were named, but they are not.

The names of the signs are abbreviated as follows (the horizontal line over the final letter is a standard medieval way of indicating abbreviations):

ARIĒ	TAV̄	GĒ	CĀ	LEO	VIRḠ
LIBRA	SCOR̄	SAḠ	CAP̄	AQR̄	PISCĒ

Alas, these forms tell us nothing about the provenance. (In recent years, regional forms of medieval Latin and dialects of vernaculars on instruments have been exploited to establish provenance.[40])

The scale of the rete is divided for each pair of signs into three parts, each subdivided into four parts—see **Fig. 8a**. This is a mistake: each 10° would be more happily divided into *five* sections. The placement of the ecliptic with respect to the outer frame is accurate. However, the lower part of the vertical bar is about 1° to the right of where it should be: see **Fig. 1**.

2.4 The star-pointers on the rete

There are four unnamed star-pointers shaped like *fleurs-de-lys* with long, limpid stems. No other medieval astrolabe comes to mind with pointers of this shape.

There are only four pointers, one in each of the four quadrants. This use of only one star in each quadrant is not without parallel: the "Toledo astrolabe", dating from *ca*. 1300, is a piece prepared by a Jew, partly finished by a Christian, and then finished off by a Muslim Arab: the last-mentioned added the Arabic names of some stars, choosing only four, one in each quadrant.[41]

The omission of the star-names is not tragic on a standard astrolabe with just a few star-pointers: every potential serious user would have known which of 20- or 30-odd "astrolabe stars" were intended,[42] and one could not read star-names at night anyway. The earliest European astrolabe, from 10th-century Catalonia, bears no star-names, probably because the

[40] See King, *Ciphers of the Monks*, p. 365, n. 6, and now n. 83 to **XIIIa-10** and the preface to **XVIII**, where various philological studies of inscriptions on astrolabes by Kurt Maier are mentioned**.**

[41] See King, "Medieval Spanish Astrolabe with Inscriptions in Latin, Hebrew and Arabic", pp. 36 and 74-75, now in **XV-2.9** and **3.15**.

[42] On the most commonly used stars on astrolabes, see Kunitzsch, *Sternnamen in Europa*, pp. 59-96.

Figs. 8a-c: Various detailed shots of the ecliptic arc and the altitude circles and markings for the seasonal hours underneath. [Photos by the author, courtesy of the Museum of the History of Science, Oxford.]

maker could not write the names.[43] However, the omission of star-names on an instrument of this non-standard variety—so that one has to decide for oneself first whether the pointer serves a star derived by a northern or southern projection—can only strengthen the impression that the maker was barely in control of his task.

The stars on the Oxford astrolabe have been chosen so that their positions are roughly symmetrical with respect to the vertical diameter. The stars in question are so well known as medieval astrolabe stars that any medieval astronomer worth his salt could identify them immediately, but only by realizing that their positions are for a northern projection, as on a standard astrolabe. (When medieval instrument-makers combined star-pointers based on both of the northern and southern projections they had to be *very* careful.[44]) To include any stars without their names was perhaps a little unkind, but there is not much space available for the names, so presumably this was deliberate. Already Gunther recognized the stars in question,[45] namely:

lower left	[Aldebaran	α Tauri]
lower right	[Regulus	α Leonis]
upper right	[Alhave	α Ophiuchi]
upper left	[Altair	α Aquilae]

[43] King, "The Oldest European Astrolabe", p. 366.

[44] Compare the retes on the spectacular 14th-century universal astrolabe of Ibn al-Sarrāj of Aleppo (#140—refs. in n. 23) and the problematic 14th-century geared astrolabe from Northern France (#198—refs. in n. 19), both discussed in Stautz, *Mathematisch-astronomische Darstellungen auf mittelalterlichen Instrumenten*, pp. 69 and 213, and 103-104 and 262, respectively.

[45] On these four standard "astrolabe stars" see Kunitzsch, *Arabische Sternnamen in Europa*, no. 18 on p. 70; no. 30 on p. 76; no. 51 on p. 81; and no. 54 on pp. 81-82.

Note that Regulus is appropriately shown on the ecliptic at longitude Leo 20°, which does correspond to *ca*. 1300, but not too much should be concluded from this alone. In fact, however, the four pointers correspond to the accurate positions of these four stars *for a northern projection* for epoch 1300 to within 1-2 mm on the instrument itself.[46] For a medieval European instrument, this may be regarded as something of an achievement.

2.5 The latitude-dependent markings on the mater

The main astrolabic markings on the mater represent the altitude circles for each 6° above and below the horizon for a latitude that is not specified, but which is, by inspection, 24°: see **Fig. 9a** and **c**. This is most easily demonstrated by the fact that the small circle for the zenith lies on the inner circle for the (summer) solstice. The altitude circles are not properly engraved for they are not uniformly spaced. Also, there are not 14 circles between the horizon and the zenith as there should be for such a "sextile" plate.

In addition, there are curves for the seasonal hours below the horizon that are appropriately drawn as arcs of circles—see **Fig. 9a**. Above the horizon, the arcs for the first and eleventh hours and the rectilinear segments engraved more heavily for the other hours are unlikely to be a later addition for the same hand also highlighted the horizon. For the "upper" hours there are two sets of markings, the other set lightly engraved as arcs of circles, like the altitude circles, and dotted—see **Figs. 9b-c**. Both sets are restricted to the domain between the equinoctial and solstitial circles. It seems that our maker has tried to engrave the markings for the astrological doctrine known as "casting the rays",[47] which were an occasional feature of Islamic astrolabes from the 10th century onwards and European instruments some centuries later. The resulting *ensalata mista* of curves and lines on an instrument of this size was calculated to confuse.

In places, the markings on the mater appear to be worn down, as if by excessive use—see further **2.7** below.

2.6 The back of the astrolabe

On the back of the instrument, within the smallest of several circular arcs inside the outer scale, the upper half bears a double universal horary quadrant and the lower half a double shadow square to base 12, with scales divided and labelled for each 3 digits and subdivided for each single digit—see further below on these markings. The alidade is counter-changed and bears two sights with a correctly-aligned cylindrical hole in each: it shows every sign of being original. One end is slightly longer than the other. The markings on the back have, like the mater, a worn look about them: see further **2.7**.

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[46] See the techniques outlined in Stautz, *Mathematisch-astronomische Darstellungen auf mittelalterlichen Instrumenten*. This piece is not discussed by Stautz.

[47] See, for example, the article "Tasyīr" by Otto Schirmer in EI_2; and North, *Horoscopes and History*, pp. 1-69. On the earliest Islamic astrolabe with markings for the houses—that of al-Khujandī made in Baghdad in 374 H [= 984/85] (#111)—see King, "Kuwait Astrolabes", Fig. 10 on p. 84, and p. 87, now in **XIIIc-9**. The oldest European astrolabe with such markings—Italy (?), 13th (?) century—is probably #558 (see n. 7 above). They were particular popular on Renaissance instruments, such as those mentioned in nn. 26 and 37: see King & Turner, "Regiomontanus' Astrolabe", pp. 171, or King, "Urbino Astrolabe", p. 115 (*ad* #640); and *ibid*., pp. 107 and 132 (*ad* #4506).
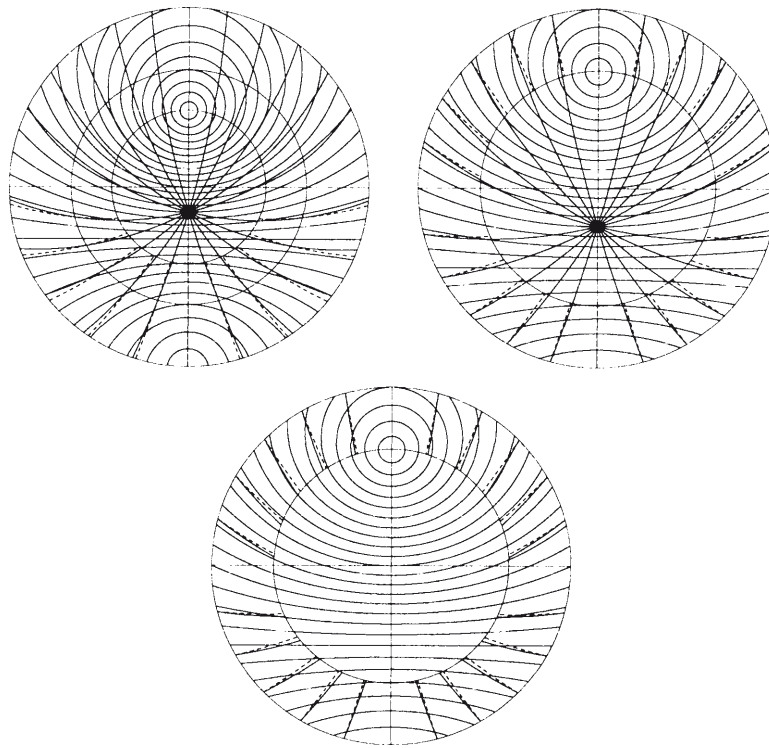
Fig. 9: (a) A set of standard markings for latitude 24° (see Fig. 5) with curves for the seasonal hours below the horizon and additional curves for the astrological houses. (b) Altitude circles above and below the horizon, bounded by the celestial equator, to serve a myrtle rete, with additional curves for the hours and for the houses. (c) A reconstruction of the marks on the Oxford plate, with the curves for the astrological doctrine of casting the rays only in the region between the inner solstitial circle and the bounding celestial equator. [Graphics by Dr. François Charette.]

Some remarks on the universal horary quadrant are in order, not least because of the misunderstanding currently associated with these markings in some circles. The device, invented in Baghdad in the 9th century, serves to find for any latitude the time in seasonal hours from the instantaneous altitude of the sun and its meridian altitude (see **XIIa**). One sets the alidade to the meridian solar altitude and makes a mark with ink or wax on the alidade at the point where it intersects the semicircle representing the 6th hour; one then moves the alidade down to the instantaneous solar altitude, and the mark indicates the time on the other hour curves.[48] The result is approximate but the error in Mediterranean and Nilotic climes (such as latitude 24°!) is minimal and more substantial in Northern Europe. In the Renaissance, some astronomers added a solar scale on the alidade of their astrolabes, which was necessarily latitude dependent. In some modern writings, this kind of scale is considered indispensable;[49] in fact, a radial solar scale is not only unnecessary but also inappropriate, because it compromises the universality of the quadrant.

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[48] The only modern work on the astrolabe in which this procedure is correctly described is García Franco, *Astrolabios en España*, pp. 218-221, esp. p. 219.

[49] North, "The Astrolabe", figure on p. 105 (fig. 16 on p. 216 of the reprint); and *idem*, "Hour-Angle Ritual".

It is perhaps significant that there is no solar scale on the back of the Oxford astrolabe, whereas there are on the vast majority of medieval European astrolabes. Such scales were uncommon on early *Eastern* Islamic astrolabes, although they are mentioned by al-Bīrūnī in the early 11th century, and, for example, one is to be found on the back of the universal astrolabe of Ibn al-Sarrāj (#140—see **1.4** and **Fig. XIVb-5.1**). The fact that they appear on the earliest surviving *Western* Islamic astrolabe, 10th century?),[50] on most Andalusī and Maghribi astrolabes from the 11th century onwards, as well as on the earliest European astrolabe (#3042), has led to some speculation concerning their origin.[51]

2.7 Is the Oxford astrolabe a fake?

Added in proof in February, 2005: The following remarks, written in 2002, should be read in the light of the evidence of another instrument from the same workshop discovered in 2005: see **2.9** below.

In recent times, there have been some serious cases of misidentification of genuine astrolabes as fakes, and of fake astrolabes as genuine.[52] We tread on particularly dangerous ground when we dismiss as a fake a given piece that we do not fully understand, not least because it is never possible to fully restore a lost reputation.

Now Gunther records that the Oxford astrolabe was "formerly gilt", and somehow a rather high proportion of gilt instruments do tend to be fake. Also, we know it surfaced in Italy only at the end of the 19th century, so it has no earlier attested provenance. I am nevertheless inclined to dismiss outright the possibility that the Oxford astrolabe is, say, a 19th-century Italian "fake". First, it feels very much like a medieval astrolabe. Second, there were plenty of standard medieval astrolabes available in Italy for a 19th-century faker to copy. Third, one needs to know a lot about astrolabes to even begin copying an instrument of this potential complexity, even if one does make a mess of it. And fourth, if an instrument is a 19th-century copy of a genuine medieval instrument, this is usually immediately apparent. But not always ... .

One thinks of the astrolabe (#4507), inevitably in gilt brass, in the Museo Bargello in Florence, which could be 15th-century or 19th-century Italian.[53] Whatever it may be, the rete on the Bargello astrolabe was originally inspired, not necessarily directly, by the kind of rete found on an 11th-century Andalusī astrolabe now preserved in Berlin (#116),[54] and its historical importance lies mainly in that fact. But one thinks also of the earliest European astrolabe from 10th-century Catalonia (#3042). One reason I proposed for its not being a fake was that: "any faker who made this astrolabe knew more about the history of the astrolabe and about Latin

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[50] Inadvertently listed twice in Gunther, *Astrolabes*, I, p. 244 (no. 110: "Early Arabian astrolabe—Undated"), and Fig. 117 (front), and p. 280 (no. 135: "Spanish astrolabe—XIIIth-XIVth Cent."). See also **Figs. XIIIa-1.2-3.**

[51] King, "The Oldest European Astrolabe", pp. 376 and 384.

[52] See n. 26.

[53] See Mara Miniati in *Florence MNB 1991 Catalogue*, pp. 48-54 (no. 22), with a full set of illustrations of the Bargello piece.

[54] Compare the two retes illustrated in King, "The Oldest European Astrolabe", figs. 6 and 19, and now **Figs. X-4.1.3-4**. On the star-positions on the Andalusī and Italian retes see Stautz, *Mathematisch-astronomische Darstellungen auf mittelalterlichen Instrumenten*, pp. 57 and 191, and 86-87 and 247.

epigraphy than all of the scholars who have ever looked at this piece ... put together."[55] The same holds for the Oxford astrolabe.

A different situation holds for the Florence astrolabe fondly called "the astrolabe of Pope Sylvester II" (#101).[56] Here we are dealing with a genuine Islamic astrolabe from 10th-century al-ʿIrāq, to which someone has added a medieval-looking solar scale on the back inscribed in Latin. The markings on the back are faked, probably 19th century Italian.

Now, metal analysis might eventually establish that the Oxford piece is indeed a 19th-century production, *deliberately* made to look as though it had been extensively used. In this case, the maker *surely* copied it from a genuine medieval instrument, *possibly* one with a complete set of plates for the climates. That genuine instrument would have been copied from an Islamic astrolabe, most *probably* one with such a complete set of plates.

It makes more sense that a 19th-century faker would provide an instrument too small to use properly with a "useless" set of markings for latitude 24° rather than a 13th- or 14th-century astrolabist. Certainly, a 19th-century faker could not have copied this piece from an instrument with inscriptions in Arabic. Another impediment to the evaluation of this instrument is that, unlike the vast majority of medieval instruments, it gives the impression of having been used. Substantial parts of the altitude markings on the mater and the surface of the back are worn away, apparently by excessive "use". Given the fact that the front of this pretty little instrument is quite useless for any sensible purpose in Italy, it seems highly unlikely that anybody other than a faker would have made it look used.

In any case, if the instrument is a "fake", it has the unusual characteristic of now being of greater historical value than any "real" instrument from which it was copied, for that is apparently lost for all time. Under no circumstances does it decrease in historical value if it *is* a 19th-century copy of a medieval instrument, and I suggest that we keep on regarding it as "medieval", whether it is or not.

2.8 Concluding remarks (2003)

The Oxford astrolabe is remarkable as the sole surviving *medieval* European instrument with a half myrtle ecliptic with double graduation. Furthermore, it is one of only two medieval European astrolabes featuring the equivalent of altitude circles *below* the horizon, although this may not be historically significant.[57] (This, as is well known, is a feature of some of the earliest astronomical clocks in medieval Europe.) The piece also has the kind of rete usually associated with universal astrolabes, but the "universality" in this case, as with some of the earliest

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[55] King, "The Oldest European Astrolabe", p. 362.

[56] Gunther, *Astrolabes*, I, pp. 230-231 (no. 101) and pl. LIIb; also García Franco, *Astrolabios en España*, pp. 131-152 (no. 3); King, "Medieval Instruments and their Secrets", p. 35; and *idem*, "Astronomical Instruments between East and West", p. 171. The instrument has been featured in several exhibitions, although already Gunther recognized the dubious character of the markings on the back. See now **XIIIb-6**.

[57] See the text to n. 20. On the 14th-century French geared astrolabe (n. 19), the altitude circles are above the horizon for a southern projection, and hence correspond to those below the horizon for a standard northern projection. On an 11th-century Andalusī astrolabe, we find altitude circles for latitude $16^1/_2$° *south*, this being the lower limit for Ptolemy's world-maps: see King, "Geography of Astrolabes", pp. 19 and 53, now in **XVI-II**, also **Fig. 11.1**.

European astrolabes,[58] was originally achieved by a series of plates for each climate.

Our astrolabe is degenerate in the sense that, from a practical point of view, it is quite useless in European latitudes. Whether it is a genuine piece from *ca*. 1300, or a copy of such a piece from the 19th century, the question arises: why would any European make such an instrument *ca*. 1300? The answer appears to be that he was a fairly competent craftsman who had, however, only a very vague idea about non-standard astrolabes. He was clearly copying, reproducing, imitating—call it what you will—another instrument, and the only sensible explanation would appear to be that he was copying an instrument which had plates for each of the seven climates of Antiquity: from this he copied only the plate for the second climate.

It is tempting to suppose that our maker was copying an Eastern Islamic instrument with inscriptions in Arabic. This would explain why the star-pointers are not named, the latitude is not specified, and there is no solar scale on the back. There is no known Islamic precedent for precisely such an instrument, but there is evidence of both components. Indeed, it is not unreasonable to hypothesize that some Muslim skilled in astrolabe design had proposed a double half myrtle rete in the "new" Islamic tradition of the 9th and early 10th century, together with a set of plates for each of the climates in the "old" tradition of Antiquity. This latter tradition is also attested on the earliest Islamic astrolabe from the 8th century (**XIIIb-2.5** and **3.11**), as well as on a badly corroded Abbasid astrolabe (**XIIIb-4**) and a solitary Abbasid plate that ended up inside the astrolabe of the Yemeni Sultan al-Ashraf (**XIIIc-12.2** and **XIVa-2**), but not on surviving astrolabes from late-9th- and 10th-century Baghdad (**XIIIc-1-9**). Thus it is further reasonable to suspect an early, say, early-10th-century, origin for this hypothetical combination.[59] The resulting instrument would be universal in the same sense as the standard astrolabe with a set of plates for the climates is universal (see **1.2**): it is not a "universal astrolabe" in the traditional sense, working for any latitude. The star-pointers would surely have been carefully labelled in order to show whether they corresponded to a northern or southern projection. Furthermore, the back of such a hypothetical Eastern Islamic astrolabe would probably not have had a solar scale. On the other hand, it is unlikely that a serious early Islamic astrolabe would have been made as small as the Oxford astrolabe (see **XIIIa-3.2**).

The milieu of the original transmission to the maker of the Oxford astrolabe may well have been Sicily, although some Islamic scientific materials appear to have come to Italy directly from Egypt.[60] An alternative proposal, namely, that any European had first hit upon this idea and was able to execute it properly, is, in the light of our present limited knowledge of the history of the astrolabe, particularly in medieval Italy, unlikely.

In brief, this little instrument presents us with a series of problems that we are—at this time—unable to solve. And it gently reminds us how little we know about the fates and fortunes of even the standard astrolabe in medieval Italy.

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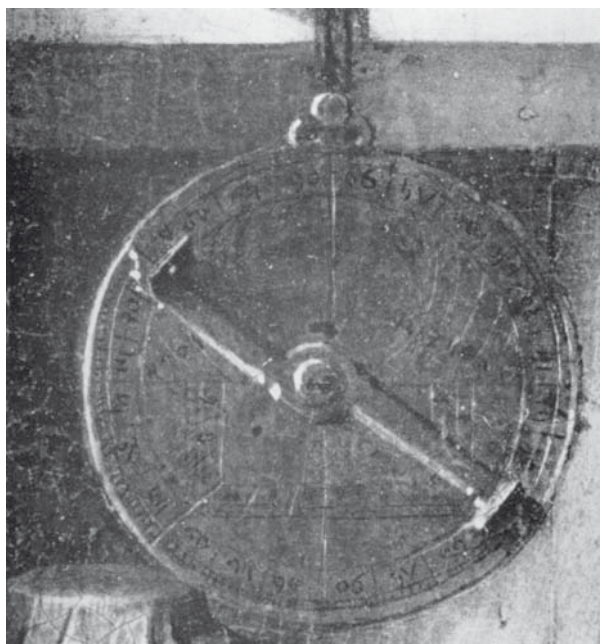
[58] King, "Geography of Astrolabes", pp. 27-28, now in **XVI-Ad**; and *idem*, *Ciphers of the Monks*, pp. 411-415.

[59] King, "Geography of Astrolabes", pp. 7-8, now in **XVI-2**.

[60] We are reminded of the planetarium described in various medieval Italian manuscripts in Latin that John North has associated with Egypt. See North, "*Opus quarundam rotarum mirabilium*", esp. p. 364 (p. 162 of the reprint).

2.9 Concluding remarks (2005)

Whilst excavating papers in my office at Frankfurt University during February, 2005, just taking a break from proof-reading, I came across a very, very bad photocopy of the back of what I thought at first sight was this little astrolabe. It turned out to be a blown-up photocopy from *ca*. 1980 of the astrolabe depicted in the exquisite painting *St. Jerome in his study* associated with Jan van Eyck (*ca*. 1390-1441), apparently finished by Petrus Christus after van Eyck's death. This painting, which is now in The Detroit Institute of Arts, depicts the saint with a friendly lion at his feet, together with a bookcase supporting various symbolic objects, one of which being the astrolabe, alas very dark: see **Figs. 10a-b**.[61] The painting measures but 20 × 12 cms. *The astrolabe*

Figs. 10a-b: Jan van Eyck's *St. Jerome in his study*, and an enlarged detail of the astrolabe, alas of poor quality. [Reproduced in haste from a 1980 photocopy of Hall, "More about the Detroit van Eyck", figs. 1 and 2.]

[61] The art historian Edwin Hall published a paper dealing with this astrolabe in 1971, listed as "More about the Detroit van Eyck". Hall certainly did some homework on astrolabes, but only in an armchair fashion, using Gunther's second volume, which contains particularly detailed descriptions on instruments at the Museum of the History of Science at Oxford. Hall mentioned several pieces, all of them, as it happens, irrelevant to his

on the painting has a diameter just less than 2 cm (!), *but one can still see the numbers on the main divisions of its scales* (!!) *and even the subdivisions* (!!!).

The astrolabe in the painting was copied from a twin of our little Italian astrolabe. I shall refer to the former as the "Detroit astrolabe". The latter differs from the actual astrolabe from which it was copied only in size: although the astrolabe is shown almost as large as the saint's head, I shall show that the model was *probably less than 6 cms in diameter*. Then the throne and the makeup of the back, with a double universal horary quadrant and a double shadow square, are very similar though not identical. The alidade is of the same kind and shape. Lastly, and most significant, the distinctive numerals on the outer scale are very similar to those on the Oxford astrolabe (remember we are dealing with a painting of an original astrolabe). But there are several important differences, namely:

- ❖ the Detroit astrolabe has a vertical diameter, not found on the Oxford piece;
- ❖ the horary markings and shadow scales are not shown within an empty annulus, as on the Oxford piece;
- ❖ the horary markings on the former are not drawn properly (but let's be reasonable!); actually they resemble horary markings for a fixed latitude, but these they are not, for there is no solar scale;
- ❖ the shadow scale on the former is labelled for each 4 digits (4-8-12, only on the left vertical), whereas the Oxford scales are labelled for each 3 digits;
- ❖ the scales on the former are labelled for each 15°, whereas those on the latter are labelled for each 10°;
- ❖ the Detroit numerals on the right-hand side are inverted with respect to those on the left-hand side, which are as the numerals on the Oxford piece.

The fact that the numerals on the right-hand side of the painting are upside down may mean that they were like this on the original. The artist would have been crazy to paint numbers upside down unnecessarily.

The Oxford astrolabe has markings for each 10° because it is so small; the implication is that the model for the Detroit astrolabe was even smaller. The subdivisions on the Oxford astrolabe are for each 2°; one could anticipate that those on the piece that served the artist for the Detroit image would have been for each 3°, although he has made a bold attempt to display about 7 subdivisions in some 15°-intervals. This was basically not a good idea, but it probably reflects what the artist actually saw on the astrolabe: in other words, the 15°-intervals on his model were indeed divided into rough 2°-intervals. In addition, in the upper left quadrant there seem to be seven divisions rather than the six that one would expect, the middle one fully obscured by the pointer on the alidade. The alidade is roughly at the midway position between vertical and horizontal.

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subject. Alas, Gunther did not illustrate the back of his "Sicilian" astrolabe #169, and Hall got carried away with #168, a Franco-Italian piece that happens to have a solar / calendrical scale on the back. With considerable enthusiasm, Hall claimed that the setting of the Detroit alidade to about 40° above the left-hand half of the horizontal axis (he mistakenly thought that the other end of the alidade was broken) signified a date early in August (on a calendrical scale that was not there), which in turn corresponded nicely with the date of the Arras Congress on August 5th, 1435.

There are various theories about the provenance of this painting, all of which I refrain from mentioning, save that it has been suggested that we have here a portrait of Cardinal Niccolò Albergati who visited Bruges in 1431 and participated in the Congress of Arras in 1435 (although portraits of him by van Eyck are different). All that I can add to the discussion is that *the astrolabe in this Flemish painting is Italian in provenance* and that *it possibly came from the same medieval Italian workshop as our Oxford astrolabe*.

The presence of the Detroit image confirms the authenticity of a hypothetical medieval astrolabe from which the Oxford astrolabe was copied, perhaps already in the Middle Ages. The principal common features of the two pieces are:

- ❖ the size (the Oxford piece is the smallest surviving European astrolabe, and the model for the Detroit picture may have been even smaller);
- ❖ the simple tri-lobed throne (typical of the earliest European instruments);
- ❖ the outer scales divided into 10° or 15° (all known medieval instruments have divisions for 5°);
- ❖ a double universal horary quadrant above the horizontal axis; and
- ❖ a double shadow square to base 12 with divisions for each 3 or 4 digits;
- ❖ no solar / calendrical scale (very unusual on medieval European astrolabes);
- ❖ a distinctive set of numerals 1-9, with 1 shaped like "I", Gothic 4, 5, and 7, and round 0 and 8.

Maybe the artist did not feature the front of the astrolabe because it looked a bit funny. If the original that he copied ever shows up in an antique store in Bruges or Arras or back in Italy, I would expect to find on it:

- ❖ a set of plates for the climates, and
- ❖ a double myrtle ecliptic on the rete (which does indeed look a bit weird).

One last thought: Perhaps the Cardinal travelled with such an astrolabe, in which case, one can hope that it was fitted with a plate for the 5th climate, which would serve Rome, and one for the 7th climate which could be used in Flanders.[62] If it had only a plate for the 2nd climate, he could as well have given it to van Eyck.

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[62] For Jerusalem, where he actually worked (as prior of the Church of the Santa Croce), he would theoretically have had to use the mean of the results obtained with plates for the 3rd and 4th climates. In practice, with such a small instrument, the results would be to all intents and purposes the same anyway. In actual practice, one would do better to look for a more appropriate instrument.

Part XIIIe

On the origin of the astrolabe according to the medieval Islamic sources

To Dimitri Gutas,
in memory of happy times spent together in Cairo
and many other places

DEDICATION,
ACKNOWLEDGEMENTS AND NOTES TO THIS VERSION

The passage on the invention of the astrolabe in the Taymūr *ḥikma* manuscript (**10**) was noticed by Dimitri Gutas in the Egyptian National Library one bitterly cold day in the winter of 1975. The other passages recorded in these pages were collected on more lonely occasions since then. This study is dedicated to the memory of the happy times spent with Dimitri in Cairo and elsewhere. Well I remember the day we met—we were both graduate students at Yale at the time—and Dimitri told me that he had started to learn Arabic. Since then our paths have crossed many times in many places, but the best of the "good old days", at least for me, were the times we spent together in Cairo, recovering from the rigours of mornings in the Dār al-Kutub, and rinsing away the dust inhaled from the manuscripts. Dimitri is now Professor of Arabic Language and Literature at Yale University, one of the world's leading Arabists and historians of Islamic civilization.

This study first appeared with the same title in *Journal of the History of Arabic Science* 5 (1981), pp. 43-83, and was reprinted in my *Islamic Astronomical Instruments*, London: Variorum, 1987, III. I do not hesitate to include it again here because the materials presented—etymologies of a loan word and attributions of an instrument from hoary Antiquity—give us insight into aspects of intellectual life in Islamic societies and the transmission of information, true and false. Alongside all the serious technical literature on the astrolabe compiled in Arabic over the centuries, there existed the sort of naïve folklore presented in this study. Some of it is certainly more serious than the rest, and it is comforting that some of the leading scientists knew what they were talking about. But all of the authors were serious about what they wrote, and it is for this reason that their opinions should be recorded. It is rather pathetic that so few scholars other than the leading scientists realized that with *asṭurlāb* they were dealing with an Arabicization of a Greek word.

The research on medieval Islamic science conducted at the American Research Center in Egypt during 1972-79 was sponsored mainly by the Smithsonian Institution and National Science Foundation, Washington, D.C. (1972-79), and by the Ford Foundation (1976-79). This support is gratefully acknowledged.

It is a pleasure to record my gratitude to the Egyptian National Library, where most of the manuscripts used in this study are preserved, and also to the Municipal Library in Alexandria, the Süleymaniye Library in Istanbul, the Universiteitsbibliotheek in Leiden, the British Library in London, Columbia University Library in New York, and the Bibliothèque Nationale in Paris. The late Professor Franz Rosenthal of Yale University and Dr. Michael Carter of the University of Sydney kindly read this study before it was published, and their valuable comments on certain linguistic and stylistic matters were incorporated already in the first version. Further comments of a more technical nature by Professor Paul Kunitzsch of the University of Munich have also been included. Any shortcomings are of course my own responsibility. The Arabic

texts were typed afresh, this time into a computer, by Petra Schmidl and Mónica Herrera, and then edited by Petra Schmidl and myself. The reader should bear in mind that we had no copies of the original manuscripts available to us during this operation.

In this version, I have not updated the bio-bibliographical references, except where this was essential, as in the case of the *Cairo ENL Survey* and EI_2. The reader should keep in mind that some of the original references may now be 20 years out of date. And, of course, as we know now, thanks to the researches of Professor Paul Kunitzsch of Munich, Messahalla does not deserve to be in first place (see his "On the Authenticity of the Treatise on the Composition and Use of the Astrolabe Ascribed to Messahalla", *AIHS* 31 (1981), pp. 42-62, repr. in *idem*, *Studies*, X). The reader is also recommended to two other studies by Paul Kunitzsch which appeared about the same time as my own, and which are quite independent of it, treating different terminology associated with the astrolabe. These are "Observations on the Arabic Reception of the Astrolabe", *AIHS* 31 (1981), pp. 243-252, and "Remarks regarding the Terminology of the Astrolabe", *ZGAIW* 1 (1984), pp. 55-60, both repr. in *idem*, *Studies*, VII-VIII. For the strong of heart there is also his "Glossar der arabischen Fachausdrücke in der mittelalterlichen europäischen Astrolabliteratur", *Nachrichten der Akademie der Wissenschaften in Göttingen*, I. Philologisch-Historische Klasse, Jahrgang 1982, Nr. 11, pp. 455-571 (separatum paginated 1-117), in which, as we shall see, he addressed some of the Latin sources on the origin of the term *astrolabium*, based on Arabic originals.

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0 Introductory remarks

> "The fables of (the) invention (of the astrolabe) by Abraham, Solomon, Enoch, or by a certain person named Lab, are unworthy of notice." William H. Morley, *The Astrolabe of Shāh Ḥusayn* (1856), p. 5.

The medieval Arabic word *asṭurlāb* or, more correctly, *aṣṭurlāb*, for astrolabe was derived from the Greek αστρολαβοσ (or αστρολαβον οργανον), name of several instruments serving various purposes, including the demonstration and graphical solution of many problems of spherical astronomy.[1] As Otto Neugebauer showed in a section on the early history of the astrolabe in his monumental *History of Ancient Mathematical Astronomy*, the underlying theory of stereographic projection was known in the time of Hipparchus (*ca*. 150 B.C.E.), and the astrolabe as it was known in medieval times was probably first described by Theon of Alexandria (*ca*. 375 C.E.).[2]

The purpose of this study is to draw attention to a series of statements in the medieval Islamic sources about the etymology of the Arabic word *asṭurlāb* or *aṣṭurlāb* and about the invention of the instrument. These statements are here discussed in chronological order, as far as possible. The original Arabic and Persian texts are presented in the **Appendix**. A few of these statements have been discussed previously by Eilhard Wiedemann (1909),[3] Franz Rosenthal (1950),[4] Schlomo Pines (1964),[5] Suʿād Māhir (1968),[6] E. S. Kennedy (1976),[7] Fuat Sezgin (1978),[8] and Paul Kunitzsch (1981).[9] Also, Solomon Gandz (1927) has made a very useful survey of the references to the astrolabe in medieval Jewish literature.[10]

In some Arabic texts from al-Andalus, such as the lost original of the Latin Messahalla (**1**), and an anonymous one (by Ibn al-Zarqālluh) (**9**), we find the statement that *asṭurlāb* means *akhdh al-kawākib*, literally "taking the stars". This corresponds to an interpretation of the Greek, assuming that the second element λαβον comes from the verb λαμβανειν, "to take",

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[1] In general, *aṣṭurlāb* is preferred in early treatises, even in late copies thereof, and *aṣṭurlāb* is standard in late treatises. On the Greek name for the astrolabe, see also Segonds, *Philipon sur l'astrolabe*, pp. 18-25.

[2] See Neugebauer, *HAMA*, II, pp. 868-879, and also *idem*, "The Early History of the Astrolabe".

[3] Wiedemann records the etymologies of al-Bīrūnī (**7**), Abū ʿAbdallāh al-Khwārizmī (*Mafātīḥal-ʿulūm*) (**3**), and Ḥājjī Khalīfa (**27**): see his *Aufsätze*, I, p. 551, and II, p. 459.

[4] Rosenthal, "Al-Asṭurlâbî and as-Samaw'al on Scientific Progress", p. 555, mentioned the derivation of *aṣṭurlāb* from *asṭur* and *Lāb* suggested by Abū ʿAbdallāh al-Khwārizmī (**3**) and Ibn Khallikān (**12**).

[5] Pines discussed the etymologies of Abū ʿAbdallāh al-Khwārizmī (**3**) and al-Bīrūnī (**7**): see his "al-Bīrūnī on the Terms *Astronomy* and *Astrology*", pp. 346-347.

[6] Maher cited and reproduced the text of the derivations in the marginalia by Isḥāq al-Zarkānī (**29**) to the anonymous treatise in 15 *faṣl*s, and in the fifth *maqāla* of the treatise by Munajjimak (**28**): see her *The Navy in Islamic Egypt* (in Arabic), pp. 255-256 and 386-387.

[7] E. S. Kennedy discussed the statements of al-Bīrūnī (**7**) in his *Shadows*: see al-Bīrūnī, *On Shadows*, text, p. 69, trans., p. 111, comm., p. 53.

[8] F. Sezgin in his monumental bio-bibliographical survey of early Islamic literature (*GAS*, VI, p. 78) discussed the attribution of the astrolabe to Hipparchus in the treatise *al-Miqyās al-murajjaḥ* (**8**), which is falsely attributed to al-Bīrūnī.

[9] Kunitzsch, "Fachausdrücke der Astrolabliteratur", pp. 470-471. See further **4*** and the concluding remarks below.

[10] Gandz, "The Astrolabe in Jewish Literature", contains references to the etymologies of Messahalla (**1**), Ḥājjī Khalīfa (**27**), and Lane (see n. 84). The supposed reference to an etymology by ʿAlī ibn ʿĪsā (p. 475) in fact relates to Abū ʿAbdallāh al-Khwārizmī.

with past stem λαβ. In Persian the phrase *akhdh al-kawākib* can be conveniently rendered *sitāra yāb*, the Indo-Iranian *sitāra* meaning "star" and *yāb* being from the verb *yāftan*, meaning "to find" or "to take". Ḥamza al-Iṣfahānī (**6**) states that *asṭurlāb* is an Arabicization of this Persian phrase. Thus the Andalusī authors were quoting as yet unidentified Eastern Islamic sources.

Kūshyār (**5**) explains *asṭurlāb* as meaning *mīzān al-shams,* "balance of the sun". This is curious not least because *mīzān al-shams* is attested in early *scientific* Arabic as referring to a special variety of sundial.[11] The Persian equivalent *tarāzū-ye afnāb* is mentioned by Muḥammad ibn Ayyūb Ṭabarī (**10a**). Abū ʿAbdallāh al-Khwārizmī (**3**) and al-Bīrūnī (**7**) explain *asṭurlāb* as meaning *mirʿāt al-shams,* "mirror of the sun", asserting that λαβον means "mirror", which is not the case. Nevertheless, the reference to the notion of a mirror is interesting not least because of the resemblance between the basic shapes of an astrolabe and a hand-mirror. In this connection I have not found any medieval Arabic explanations of the term *kursī* (whence English "throne") for the part of the astrolabe that projects outward from the main body of the instrument to bear the ring and cord by which the astrolabe can be held or suspended. The *kursī* of the astrolabe perhaps derives from the handle of a hand-mirror, an idea suggested to me by Prof. Derek de Solla Price in the 1970s.

The popular medieval Islamic attribution of the invention of the astrolabe to an individual named *Lāb*, a son of Idrīs (= Enoch), is pure fiction. This attribution occurs in the writings of Abū Naṣr al-Qummī (**2**), and is criticized already by his late contemporary Abū ʿAbdallāh al-Khwārizmī (**3**). It also occurs in the Latin translation of the commentary by ʿAlī ibn Riḍwān of the *Tetrabiblos* of Ptolemy (**4***) (I have not been able to check the original). There are other stories about Idrīs in Islamic folklore, which credit him with the invention of geomancy, the art of writing, and the craft of making garments.[12] The association with *Lāb* was popular because it provided a purely Arabic etymology of the name *asṭurlāb*. The first element *asṭur* is the plural of *saṭr*, "line", and the juxtaposition of two nouns indicates possession of the first by the second. Thus *asṭurlāb* means "lines of *Lāb*". In the later Arabic sources on *asṭurlāb*, *Lāb* becomes a son of Hermes.[13] Similarly fanciful explanations occur in medieval Jewish writings.[14] William H. Morley, in the introduction to his splendid description of the astrolabe of the Safavid Shāh Ḥusayn preserved in the British Museum (1865), wrote disparagingly about these etymologies: see the quote at the beginning of this study.

An anecdote recorded by Ibn Khallikān (**12**) about the invention of the astrolabe by Ptolemy is also fiction. Ptolemy is said to have been riding on some animal, carrying a celestial sphere in his hand; he dropped the sphere, the beast trod on it and squashed it, and the result was the astrolabe. The anecdote, which I find as charming as the story of Newton and the apple, is not new to the modern literature, because it occurs in the published text and translation of

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[11] *Cf.* Dozy, *Supplément aux dictionnaires arabes*, II, p.809, where no specific medieval context is mentioned. See, however, E. S. Kennedy's translation and commentary of a passage on an instrument for reckoning time of day called *mīzān* which is described by al-Bīrūnī in his book on shadows (al-Bīrūnī, *Shadows*, I, pp. 153-156, and II, pp. 82-83), and also the remarks in King, "Ibn Yūnus and the Pendulum", pp. 49-50, and **IV-7.5**.

[12] See the EI_2 article "Idris" by Georges Vajda.

[13] See the EI_2 article "Hirmis" by Martin Plessner.

[14] See Gandz, "The Astrolabe in Jewish Literature", pp. 480-482, on the astrolabe in Jewish Bible exegesis and in the Talmud and Halakhah.

Ibn Khallikān's biographical dictionary, but it has hitherto been overlooked by historians of science. I have no information on the origin of this anecdote.

Of greater historical interest is the statement attributed to Thābit ibn Qurra (see **4**, **7** and **8**) that the astrolabe was invented by Hipparchus. This is the first instance in the Arabic sources of a reference to Hipparchus in this connection. I have attempted to trace Thābit's source for this information to a Greek treatise on the astrolabe that has hitherto been overlooked in discussions of the early history of the astrolabe. But the statement about Hipparchus attributed to Thābit also includes a reference to *Lāb*, which would hardly occur in a Greek source. A single Persian text (**34**) associates the invention of the astrolabe with Aristotle, which is again fiction.

I make no claim to have exhausted the available Arabic sources on the origin of the astrolabe and the etymology of its name.[15] I have not ventured further than the standard lexicographical sources, although since *asṭurlāb* is not an Arabic word it is not listed in the most famous medieval Arabic dictionaries such as the *Lisān al-ʿArab* and the *Tāj al-ʿarūs*, However, I have checked all of the medieval Islamic treatises on the astrolabe currently available to me. Most medieval Muslim writers do not broach the subject of the origin of *asṭurlāb*. The following are the exceptions.

Index of names:
I present here a list of the ancient and medieval authorities cited in the main part of this study. I have numbered those for whom direct quotes are available. The corresponding Arabic and Persian texts presented in the Appendix are similarly numbered.

	Ab	31
	Hermes	24, 28
	Idrīs (Enoch)	2, 16, 24, 31, 34
	Lāb	2, 3, 8, 10, 15, 16, 19, 23, 24, 28, 34, conclusion
	Istar (Greek king)	conclusion
	Iskandar (Alexander)	34
	Aristotle	34
	Hipparchus	4, 8
	Ptolemy	4, 8, 9, 12, 14, 25, 27, 30, 31, 33
	Abywn (Απιον)	4, 7, 8
	al-Fazārī	4, 27
1	Messahalla = Pseudo-Māshāʾallāh = Maslama al-Majrīṭī	also conclusion
	Thābit ibn Qurra	4, 7, 8
2	Abū Naṣr al-Qummī	also 10, 24, 28

[15] The only list of medieval Islamic works on the astrolabe is Awad (< ʿAwwād), "Astrolabe Texts" (in Arabic), but it is severely incomplete and needs to be supplemented with various additional works found in the standard bio-bibliographical works on Islamic science by Suter, Brockelmann, Krause, Reṇaud, Storey, Sezgin, King (*Cairo ENL Survey*), Matvievskaya & Rosenfeld, İhsanoğlu *et al*., and Rosenfeld & İhsanoğlu. Kunitzsch, "Fachausdrücke der Astrolabliteratur", based on some three dozen texts in Greek, Syriac, Arabic, and Latin, deals mainly with the Arabic technical terminology of the component parts of the astrolabe.

3	Abū ʿAbdallāh al-Khwārizmī	also 27
4	Ibn al-Nadīm	also 1, 4, 7
4*	ʿAlī ibn Riḍwān	also conclusion
5	Kūshyār ibn Labbān	also 10, 11, 24, 25, 27
6	Ḥamza al-Iṣfahānī	also 7, 10, 24
	Abu ʾl-Ṣalt	*addendum*
	Ibn al-Samḥ	*addendum*
7	al-Bīrūnī	also 4, 5, 6, 10, 24, 27
8	Anonymous (*al-Miqyās al-murajjaḥ)*	
9	Ibn al-Zarqālluh	also 1
	Ibn al-Ṣaffār	1
	Maslama al-Majrīṭī	1, 33
10	al-Ḥarīrī and commentators	also 2, 5, 6, 7, 24, 32
	al-Muṭarrizī	10
10*	Muḥammad ibn Ayyūb Ṭabarī	also 32
	Hibatallāh al-Aṣṭurlābī	11, 12
11	Abū Naṣr Aḥmad ibn Zarīr (?)	
	Sharaf al-Dīn al-Ṭūsī	12
	Kamāl al-Dīn ibn Yūnus	12
	al-Jaghmīnī	10
	Naṣīr al-Dīn al-Ṭūsī	24
	Ibn al-Qifṭī	4
12	Ibn Khallikān	also 31
13	Anonymous (Maghribi or Andalusī)	
14	Mūsa ibn Ibrāhīm	
15	Ibn Jamāʿa	
16	Abū ʿAlī al-Fārisī	
17	al-Nuwayrī	also 26
18	al-Mizzī	also 19, *addendum*
19	Anonymous (*Tuḥfat al-ṭullāb*)	also 18, *addendum*
20	Sharaf al-Dīn al-Khalīlī	
21	Anonymous (spherical astrolabe treatise)	
	Geoffrey Chaucer	1
22	al-Damīrī	
23	al-Fīrūzābādī	also 10
24	al-Birjandī	also 10, 28, 29
25	Jalāl al-Dīn al-Suyūṭī	
	Johannes Stöffler	conclusion
26	al-Khafājī	also 17
27	Ḥājjī Khalīfa	
28	Munajjimak	also 24

29	Isḥāq al-Zarkānī	also 24
30	ʿAbd al-Raḥmān al-Fāsī	also 31
31	Muḥammad al-Bannānī	also 12, 22, 30
32	Jean Chardin	
33	Aḥmad Bāshā Mukhtār	
34	Ibrāhīm Farūqī	

1 Messahalla = Pseudo-Māshāʾallah = Maslama al-Majrīṭī

In the first version of this study I, like many others before me, fell into the trap of supposing that the Latin treatises on the construction of the astrolabe attributed to "Messahalla", were originally due to the late 8th/early 9th-century Baghdad astrologer Māshāʾallah.[16] In a note added in proof, I was able to point out that Paul Kunitzsch had recently shown that the Messahalla treatises appear to be based on Western Islamic compilations based on a treatise by Maslama al-Majrīṭī or some of his disciples such as Ibn al-Ṣaffār.[17] In the Latin texts there seems to be much confusion between Mezleme, *etc*., for Maslama and Messahalla, *etc*., for Māshāʾallāh. In any case, in this version, I have not moved Messahalla from first place.

The Latin treatise[18] begins: *astrolabium nomen grecum est cuius interpretatio est acceptio stellarum* ... , that is "astrolabe is a Greek word whose meaning is "taking the stars". This last expression corresponds to Arabic *akhdh al-kawākib*, which is also mentioned by Ibn al-Zarqālluh (**9**). The Latin treatise on the *use* of the astrolabe attributed to Messahalla has a different *incipit*.[19] Likewise, no etymology is offered by Geoffrey Chaucer in his treatise on the *use* of astrolabe, which is closely related to that of Messahalla.[20]

The Latin phrase *acceptio stellarum* and the equivalent *akhdh al-kawkib* used by Ibn al-Zarqalluh (**9**) derive from an Eastern Islamic tradition because Ḥamza al-Iṣfahānī (**6**), who was earlier, mentions the equivalent *Persian* phrase, albeit as the original.

2 Abū Naṣr al-Qummī

Abū Naṣr al-Ḥasan ibn ʿAlī al-Qummī was an astronomer of the late 10th century.[21] His major work was an extensive treatise entitled *al-Mudkhal ilā ʿilm aḥkām al-nujūm*, dealing mainly

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[16] On Māshāʾallāh see David Pingree's article in *DSB*, and Sezgin, *GAS*, VI, pp. 127-129, and VII, pp. 102-108. His treatise dealing with both the construction and use of the astrolabe, apparently lost, is mentioned in Ibn al-Nadīm, *al-Fihrist*, ed. Flügel, p. 273.

[17] Kunitzsch, "Messahalla on the Astrolabe". See also *idem*, "Fachausdrücke der Astrolabliteratur", pp. 470-471.

[18] *Cf.* Steinschneider, *Die arabische Literatur der Juden*, p. 18, cited in Gandz, "The Astrolabe in Jewish Literature", pp. 475-476. See also Carmody, *The Astronomical Works of Thābit ibn Qurra*, pp. 23-25, and Skeat, *Chaucer on the Astrolabe*, p. xxv.

[19] Skeat, *op*. *cit*., p. 88.

[20] *Ibid*., pp. 1-14.

[21] On al-Qummī see Sezgin, *GAS*, VII, pp. 174-175, and the works there cited. I have used MSS Cairo Ṭalʿat *mīqāt* 222,2, (fols. 60r-177r, copied 619 H) and Istanbul Fatih 3427,1 (fols. 1v-113v, 708 H) of his treatise, in which the texts of the passage are rather different. In a third copy consulted, MS Cairo Muṣṭafā Fāḍil *mīqāt*

with astrology but also containing sections on theoretical astronomy. In the second *faṣl* of the third *maqāla*, al-Qummī wrote about the astrolabe and presented an etymology of *asṭurlāb*, which was quoted by several later writers (see **10**). No doubt the fact that al-Qummī was an astronomer gave authority to his derivation of *asṭurlāb*, which was that the instrument was invented by *Lāb*, a son of Idrīs, and that when his father asked who had drawn lines on it (*man saṭarahu*?), he was told that *Lāb* had done this (*hādhā asṭuru Lāb* or *saṭarahu Lāb*), whence the name *asṭurlāb*. There is no lexical evidence for the IV^th^ form (*asṭara*) of the root *s-ṭ-r*, which occurs in one version of the text consulted.

In one of the copies of al-Qummī's treatise that I have used there is the additional fiction that *asṭur* is Greek for *mīzān* (= balance) and *lāb* for the sun, whence *asṭurlāb*, meaning *mīzān al-shams* (= balance of the sun). This etymology also occurs in later sources (see **10** and **22**).

3 Abū ʿAbdallāh al-Khwārizmī

Various etymologies of *asṭurlāb* are given by the 10th-century encyclopaedist Abū ʿAbdallāh al-Khwārizmī (not to be confused with the 9th-century astronomer) in his *Mafātīḥ al-ʿulūm*.[22] He first states that the word means *miqyās al-nujūm*, "instrument for measuring the stars", and derives the Greek *asṭurlab*on from *astar* = *najm* = star and *labon* = *mirʾā* = mirror, drawing a parallel with the Greek word *astronomia* for astronomy. He then speaks contemptuously of those who claim that *Lāb* is the name of a man and that *asṭur* is the plural of *saṭr* = *khaṭṭ* = line, stressing that the word is Greek and that its derivation from an Arabic root indicates stupidity and folly.

4 Ibn al-Nadīm

The 10th-century bibliographer Ibn al-Nadīm, states in his celebrated work known as the *Fihrist*,[23] that Ptolemy was the first to make (*ʿamala*) the astrolabe, adding that it is said that it may have been made before him but this cannot be known with certainty.[24] He goes on to say that the first person to make an astrolabe plane (*saṭṭaḥa*) was *Abywn* the Patriarch, whom he lists elsewhere as the author of a treatise on the planisphaeric astrolabe and states that he lived "a little before (the advent of) Islam or a little after."[25] Elsewhere he says that the mid-8th-century Baghdad astronomer al-Fazārī was the first person in Islam to make (*ʿamala*) an astrolabe. Ibn al-Nadīm also notes that astrolabes where made in the city of Ḥarrān and that

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208 (91 fols, *ca*. 1150 H), this section has been left out: in the introduction to the 3rd *maqāla* (fol. 34v), it is stated that the section has been omitted because it was dispensable (*turika li-'l-istighnāʾ ʿanhu*).

[22] I have used the Cairo edition of his treatise (listed as ʿAbdallāh al-Khwārizmī, *Mafātīḥ al-ʿulūm*), based on the 1895 edition of Gerlof van Vloten. On the author see the *DSB* article "al-Khuwārizmī" by Juan Vernet.

[23] On Ibn al-Nadīm see the EI_2 article by Johannes Fück.

[24] Ibn al-Nadīm, *al-Fihrist*, ed. Flügel, p. 284.

[25] *Ibid*., pp. 270 and 284.

they spread from there throughout the Abbasid Empire in the time of the Caliph al-Maʾmūn, that is, in the early 9th century.[26]

The identity of *Abywn* al-Baṭrīq is by no means certain,[27] although it seems probable that he was a Coptic patriarch, since the name Apion (= Greek Απιον) is well attested in Coptic.[28] The only other reference to *Abywn* known to me in the later Arabic scientific literature, apart from a remark by the 13th-century historian of science Ibn al-Qifṭī,[29] which is based on Ibn al-Nadīm, is in the introduction of a treatise on the use of the astrolabe by al-Bīrūnī (**7**). The treatise, entitled *Maqāla fī Taṭrīq ila ʻstiʿmāl funūn al-asṭurlābāt*, differs from al-Bīrūnī's other two treatises on the astrolabe, the *al-Istīʿāb fī ʻl-wujūh al-mumkina fī ṣināʿat al-asṭurlāb* and the *Ikhrāj mā fī quwwat al-asṭurlāb ila ʻl-fiʿl*, and is extant in a unique copy, MS Paris B.N.F. ar. 2498,1, copied *ca*. 1000 H.[30] The text is corrupt and indeed the name *Abywn* al-Baṭrīq is miscopied as *Ahwn al-ṭryq* (fol. 1r). However, al-Bīrūnī states that he had seen *Abywn*'s treatise on the astrolabe (in its Arabic translation), and notes that it contained 157 chapters and that it was translated by Thābit ibn Qurra, the celebrated scholar and translator of Baghdad at the end of the 9th century.[31] al-Bīrūnī further observes that the text used for the translation was corrupt, that Thābit had improved it where possible, and that the chapters in the book did not correspond to those listed in the table of contents. *Abywn* has previously been overlooked in studies of the early history of the astrolabe. In the section on al-Bīrūnī (**7**), I shall present evidence that *Abywn* ascribed the invention of the astrolabe to Hipparchus.

4* ʿAlī ibn Riḍwān

The Egyptian scholar Abu ʻl-Ḥasan ʿAlī ibn Riḍwān (d. 1061) wrote an extensive commentary on Ptolemy's astrological handbook known as the *Tetrabiblos*. I have not been able to consult any manuscripts of this, but Paul Kunitzsch has noted that the 16th-century German scholar Johannes Stöffler cited the 15th-century printed edition of the 13th-century Latin translation of

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[26] *Ibid*., p. 273.

[27] See Sezgin, *GAS*, VI, p. 103. The orthography *Abywn* seems acceptable. Flügel's critical apparatus indicates variant readings from two manuscripts: *Aynwn* and *Abnwn* in the first instance (p. 24), and *Abnwn* and *Axxwn* (where *z* is an unpointed carrier that can be read as a "*b*" or an "*n*" or a "y") in the second (p. 26). I assume that *Abywn* is found in the two other manuscripts used by Flügel for this section of the text (see p. 3). Flügel suggested an original Απιον (p. 24).

[28] Private communication from my friend William J. Fulco, S.J. I had previously wondered whether *Abywn* might have been identical with Ahron al-Qiss, "the priest", who wrote on medicine in Syriac about the time of the birth of Islam (cf. Sezgin, *GAS*, III, pp. 166-168) and who is also mentioned by Ibn al-Nadīm (p. 297). Although the name *Abywn* and *Ahrwn* could conceivably be confused in unpointed Arabic, this identification seems improbable.

[29] Julius Lippert, in his edition of Ibn al-Qifṭī's *Taʾrīkh al-ḥukamāʾ* (p. 71), gave the name as *Anbwn* and listed no variants.

[30] Both Suter, *MAA*, p. 99, and Boilot, "L'œuvre d'al-Beruni", no. 47, suggest that this work is the same as that found in MS Berlin Ahlwardt 5794, which is not the case. See further *Cairo ENL Survey*, no. B78/4.3.5.

[31] On Thābit see the article by B. A. Rosenfeld and A. T. Grigorian in *DSB*, and also Sezgin, *GAS*, V, pp. 254-272, and VI, pp. 163-170, esp. p. 169, no. 22. Dr. Richard Lorch has drawn my attention to the coincidence that al-Ṣūfī's treatise on the sphere also contained 157 chapters.

this, quoting an etymology of the Arabic *asṭurlāb* as *asṭur*, “lines”, of *Lāb*, a personal name.[32] This merits further investigation, although this etymology was certainly not original to ʿAlī ibn Riḍwān (**2** and **3** are earlier). It is perhaps also worth mentioning that his treatise was also translated into Persian and Turkish, although both translations appear to be rather late.[33]

5 Kūshyār ibn Labbān

Kūshyār was an astronomer and mathematician of some distinction who lived in Iran *ca*. 1000.[34] In the introduction to this treatise on the use of the astrolabe Kūshyār says that *asṭurlāb* is a Greek word and that the most common explanation of its meaning is *mīzān al-shams*, “balance of the sun”.

6 Ḥamza al-Iṣfahānī

al-Bīrūnī (**7**) informs us that the literary scholar Ḥamza al-Iṣfahānī (893 - *ca*. 970)[35] discussed the etymology of the word *asṭurlāb*, and also the word *awj* (= apogee).[36] al-Bīrūnī specifically cites al-Iṣfahānī’s work *al-Muwāzana* as the source for his information. The full title of al-Iṣfahānī’s treatise is *al-Khaṣāʾiṣ wa-’l-muwāzana bayna ‘l-ʿarabiyya wa-’l-fārisiyya*, and unfortunately the only known copy thereof[37] is incomplete and there is no reference in the surviving text of either of the terms *asṭurlāb* or *awj*. According to al-Bīrūnī (**7**), Ḥamza stated that *asṭurlāb* is an Arabicization of the Persian *satāra yāb*, “taker of the stars”.

7 al-Bīrūnī

The great 11th-century scientist Abu ‘l-Rayḥān al-Bīrūnī mentioned the etymology of the word *asṭurlāb* at least twice in his writings.[38] In the first instance that has come to my attention, namely, in his treatise on astrology entitled *al-Tafhīm fī ṣināʿat al-tanjīm*, he states that the astrolabe was a Greek instrument called *asṭurlābūn*, meaning “mirror of the stars”, which was why Ḥamza al-Iṣfahānī (**6**) had explained it as being from the Persian expression *satāra yāb*. al-Bīrūnī was not happy about this explanation, as we learn from his book on shadows entitled

[32] On ʿAlī ibn Riḍwān and his work see Sezgin, *GAS*, VII, p. 44. On the Latin translation see Carmody, *Arabic Sciences in Latin*, p. 19 (10f), with references to the Venice 1484 and 1484/85 editions (“I” on p. 13). On this quote see Kunitzsch, “Fachausdrücke der Astrolabliteratur” (see n. 9 above), p. 470.
[33] Sezgin, *op. cit*.
[34] On Kūshyār see Sezgin, *GAS*, V, pp. 343-345, VI, pp. 246-249, and VII, 182-183. I have used MS Paris BNF ar. 2487 (copied in 679 H) of his treatise.
[35] On Ḥamza al-Iṣfahānī see Sezgin, *GAS*, I, pp. 336-337, and the EI_2 article by Franz Rosenthal.
[36] al-Bīrūnī cites Ḥamza’s etymology of *awj* in his treatise *On Transits* (text, p. 17, transl., pp. 20-21).
[37] Namely, MS Cairo Dār al-Kutub *lugha* 90 (49 fols., *ca*. 700 H).
[38] On al-Bīrūnī see the *DSB* article by E. S. Kennedy; Sezgin, *GAS*, V, pp. 375-383, VI, pp. 261-276, and VII, pp. 188-192; and *Cairo ENL Survey*, no. B78.

Ifrād al-maqāl fī amr al-ẓilāl. There he states that Ḥamza in his book *al-Muwāzana* had stated that *asṭurlāb* is an Arabicized Persian word, the origin being *satāra yāb*, "taker of the stars", in Arabic *mudrik al-nujūm*, "that which comprehends the stars". al-Bīrūnī adds that this Persian name may very well have been derived from the special function of the instrument or may have been adapted (*ʿarraba* here does not mean "to render into Arabic" but rather "to borrow a word into any language") from the Greek, in the same way that Ḥamza mentioned that the Arabic expression is a Arabicization of the Persian. al-Bīrūnī indicates his knowledge that the Greek name is *asṭurlābūn* and that *astar* means "star" in Greek, as in the Greek words *astronomia* and *astrolojia*.[39] He adds that he has found ancient books on its construction and operation by the Greeks but not by other peoples, and that the people of the east (*i.e*., the Indians) do not know about the astrolabe and use only shadows.

As noted in the section on Ibn al-Nadīm (**4**), al-Bīrūnī was familiar with the treatise of *Abywn* in the translation of Thābit. See also the next section.

8 Anonymous (*al-Miqyās al-murajjaḥ*)

MS Cairo Ṭalʿat *mīqāt* 155 is a very unusual compendium of Arabic works on the astrolabe and quadrant, some of which merit detailed study.[40] The manuscript was copied in Egypt about 1650, and several of the treatises are of Maghribi origin. The first treatise (fols. lr-15v) is entitled *Kitāb al-Miqyās al-murajjaḥ fī ʿl-ʿamal bi-'l-asṭurlāb al-musaṭṭaḥ* and is attributed to Abu ʿl-Rayḥān, that is, al-Bīrūnī, but this attribution is called into question by the fact that al-Bīrūnī is mentioned in the text.[41] The treatise is divided into two *maqāla*s, parts, the first of which contains six *fuṣūl*, sections, but the Cairo manuscript breaks off in the first *faṣl* of the second *maqāla*.

The unidentified author asserts in his discussion of the origin and the meaning of the word *asṭurlāb* that Abu ʿl-Ḥasan Thābit ibn Qurra (see **4**) in a book on the use of the astrolabe had stated that Hipparchus before Ptolemy had invented (*waḍaʿa*) the astrolabe and had made it plane (*saṭṭaḥa*) in the same way as *Lāb* had done. The writer continues with a discussion of the reason why Hipparchus had chosen a northern projection. Now the only work on the astrolabe known to have been written by Thābit is a translation of the treatise by *Abywn* al-Baṭrīq (see again **4**), but it seems unlikely that a scholar of the calibre of Thābit would himself have subscribed to the story of *Lāb*, or have mentioned it without critical comment. We may perhaps conclude that the reference to Hipparchus was found already in the treatise of *Abywn*, but how could this Greek treatise have contained the nonsense about *Lāb*?

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[39] Pines, "al-Bīrūnī on the Terms *Astronomy* and *Astrology*".
[40] On the manuscript see *Cairo ENL Catalogue*, I, pp. 481-482.
[41] On this treatise see *Cairo ENL Survey*, no. B38 (illustrated in Fig. LVII on p. 277), and also Sezgin, *GAS*, VI, pp. 78 and 169.

9 Ibn al-Zarqālluh

MS Istanbul Aya Sofya 2671,5, fols. 133v-151v, copied in 621 H [= 1224], is a unique copy of an anonymous treatise on the planisphaeric astrolabe,[42] whose author can be identified as the 11th-century Toledo astronomer Ibn al-Zarqālluh (Azarquiel).[43] At the beginning of the treatise, the author states that *asṭurlāb* is a Greek word which means *akhdh al-kawākib*, "taking the stars", because by means of it the derived knowledge of the positions of the stars can be obtained. Ibn al-Zarqālluh quotes Ptolemy as stating that the astrolabe is like the celestial sphere made into a plane, with the visible pole made to be its centre. Ibn al-Zarqālluh is probably referring to the introduction of the Arabic version of Ptolemy's *Planisphaerium*, a copy of which precedes his treatise in the Aya Sofya manuscript.[44]

10 al-Ḥarīrī and commentators

The *Maqāmāt* of the 11th-century Basra litterateur al-Ḥarīrī are a classic of Arabic *belles-lettres*.[45] In this work there is no mention of any aspect of astronomy. However, a note on the etymology of *asṭurlāb* and the invention of the instrument, stated to be taken from a commentary on al-Ḥarīrī's *Maqāmāt*, is found in MS Cairo Taymūr *ḥikma* 15, p. 137, immediately preceding a copy of the treatise *Unmūdhaj al-ʿulūm* by Jalāl al-Dīn al-Dawwānī.[46] The author describes the instrument as "one for measuring the stars and the sun", stating that the first person to make it was *Lāb*, and then adding an alternative derivation from Persian (due to Ḥamza al-Iṣfahānī), in which, however, the Arabic paraphrase is based on the meaning "mirror of the stars", not on the correct meaning of the Persian. The same note is found in MS Cairo Musṭafā Fāḍil *hayʾa* 1, fol. 1r, preceding marginalia by ʿAlī Birjandī (**24**) to Qāḍī Zāde's commentary on the very popular compendium of astronomy *al-Mulakhkhaṣ fi ʻl-hayʾa* by the early-13th-century scholar al-Jaghmīnī, copied about the year 1610 in Amud, Iran. The note on *asṭurlāb* from an unspecified commentary on the *Maqāmāt* occurs together with another stated to be taken from the *Qāmūs* (of al-Fīrūzābādī (**23**)).

Another note stated to be taken from the commentary on the *Maqāmāt* by al-Muṭarrizī (*fl.*

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[42] This work, falsely attributed to Euclid on fol. 1r, is listed in Krause, "Stambuler Handschriften", p. 525, no. 15.

[43] On the author see the *DSB* article "al-Zarqālī" by Juan Vernet and the references there cited. It was not preciously known that Ibn al-Zarqālluh wrote on the regular planisphaeric astrolabe. The author of the treatise in the Aya Sofya manuscript presents a star catalogue for the year 459 H, which is precisely the date mentioned by Ibn al-Zarqālluh in one of his three treatises on the universal plate, extant in a unique copy in fols. 1r-75r of the same Aya Sofya manuscript (*cf.* fols. 10r and 148v). (On this star catalogue see now Kunitzsch, "Two Star Tables from Muslim Spain".) This particular treatise is arranged in 80 *bāb*s, as compared with his two other treatises of 60 and 100 *bāb*s: thus each of Ibn al-Zarqālluh's three treatises is known to exist in the original Arabic.

[44] *Cf.* Krause, "Stambuler Handschriften", p. 443, and Sezgin, *GAS*, V, p. 170.

[45] On al-Ḥarīrī see the article in EI_2 by D. S. Margoliouth and Ch. Pellat.

[46] On al-Dawwānī see the article in EI_2 by A. K. S. Lambton, and on his treatise see Brockelmann, *GAL*, II, p. 282.

Fig. 1: Two sets of stories about the early history of the astrolabe, one in Arabic and the other in Persian. These are discussed in **10** and **32**, respectively. [From MS Cairo Ṭalʿat *mīqāt* 255, fol. 2v, courtesy of the Egyptian National Library.]

Khwarizm and Baghdad, d. 1213)[47] occurs in Cairo Ṭalʿat *mīqāt* 255, fol. 2v, copied *ca*. 1700 amidst various notes preceding a collection of treatises on instruments and timekeeping—see **Fig. 1** and also **32** below. al-Muṭarrizī quotes successively Abu ʻl-Ḥasan (Kūshyār) (**5**), Abū Rayḥān (al-Bīrūnī) (**7**), Ḥamza al-Iṣfahānī (**6**), and Abū Naṣr (al-Qummī) (**2**).

10* Muḥammad ibn Ayyūb Ṭabarī

A new source that has come to my attention is the Persian treatise *Shish faṣl* ("Six chapters") on the use of the astrolabe by the 11th-century astronomer Muḥammad ibn Ayyūb Ṭabarī.[48] The author states that the term *asṭurlāb* is Greek and means *tarāzū-ye aftāb*, "balance of the sun". See further **32**.

Note added in proof: In October, 2004, I noticed that the Tehran edition of Ṭabarī's *Shish faṣl* also included another Persian treatise by him entitled *al-ʿAmal wa-ʼl-alqāb*. In this (p. 179) he writes that the meaning of *asṭurlāb* in Greek is *tarāzū-ye aftāb* (see **32**), in Persian *satāra yāb* (see **6-7**), and in Pahlevi *jām jahān namā*. The last, not attested in the other sources studied here, means essentially "mirror of the world", and is recorded by Steingass (*Persian Dictionary*, p. 636) as meaning, like *jām jamm*, "a mirror supposed to reflect all scenes and events", and also, appropriately, "an astrolabe", as well as "a telescope" and "the human heart".

11 Abū Naṣr Aḥmad ibn Zarīr (?)

MS Leiden Or. 591 (pp. 32-46, copied 630 H) contains a treatise on the astrolabe with a crab-shaped ecliptic on the rete (*al-asṭurlāb al-musarṭan*) by an individual named Abū Naṣr Aḥmad ibn Zarīr (?).[49] Since the author mentions the celebrated astrolabist Hibatallāh al-Asṭurlābī (*fl*. Baghdad, *ca*. 1100—see also **12**) we may presume that he lived in the 12th century. Abū Naṣr states at the beginning of his treatise that *asṭurlāb* is a Greek word, and that the astrolabe is a fine instrument and the "balance of the sun" (*mīzān al-shams*).

12 Ibn Khallikān

The celebrated 13th-century Syrian historian and literary scholar Ibn Khallikān discussed the origin of *asṭurlāb* in his biographical dictionary *Wafāyāt al-aʿyān*.[50] In his entry on Abu ʻl-Qāsim Hibatallāh al-Asṭurlābī, the famous instrument maker of late-11th/early-12th-century Baghdad (see **11**), Ibn Khallikān cites first the etymology of Kūshyār (**5**), and then presents

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[47] On al-Muṭarrizī see Brockelmann, *GAL*, I, pp. 350-352, and also p. 327. I have been unable to locate this passage in the Cairo manuscripts of al-Muṭarrizī's commentary listed by Brockelmann.

[48] On this author, also known to us by his astronomical handbook called *Zīj-i Mufrad*, see Storey, *PL*, II:1, pp. 3-4 (no. 5) and 43-44 (no. 79); Sezgin, *GAS*, V, pp. 385-386 and 404; and Rosenfeld & İhsanoğlu, *MAIC*, p. 116 (no. 301); as well as **I-3.3.3**, **II-14.2** and **IV-5.3** . His astrolabe treatise was published in Tehran in 1993 and is listed under Ṭabarī in the bibliography. The etymology occurs on p. 78.

[49] Abū Naṣr and his treatise are mentioned in Suter, *MAA*, no. 484.

an anecdote about the invention of the astrolabe by Ptolemy, introduced with the word *qīla*, "it is said that ... ". **The story is that Ptolemy was taking a ride with an armillary sphere in his hand; inevitably, he dropped it and the animal on which he was riding trod on it and squashed it: the result was an astrolabe.** Ibn Khallikān goes on to relate that neither Ptolemy nor any of the ancients realized that the sphere could also be represented on a line and that Sharaf al-Dīn al-Ṭūsī was the first to develop a linear astrolabe, later to be improved by his student Kamāl al-Dīn ibn Yūnus. Ibn Khallikān concludes this section with a discussion about the futility of trying to represent the sphere at a point!

Indeed Sharaf al-Dīn al-Ṭūsī (*fl. ca.* 1200) did devise a linear astrolabe, called *ʿaṣa ʻl-Ṭūsī*, "al-Ṭūsī's stick", which was modified by his student Ibn Yūnus, also a scholar of distinction.[51] It is of interest that Ibn Khallikān early in his career met Kamāl al-Dīn ibn Yūnus in Mosul,[52] but it seems unlikely that he would have picked up the anecdote about Ptolemy from such a serious scholar. The only other reference to the anecdote known to me in later Arabic literature is in the writings of the 18th-century Maghribi author Muḥammad al-Bannānī (**31**).

13 Anonymous (Maghribi or Andalusī)

Another etymology occurs in an anonymous Maghribi or Andalusī treatise on the astrolabe preserved in MS Cairo Dār al-Kutub *mīqāt* 1169,6 (fols. 45r-57r, copied 1158 H).[53] This treatise begins with the statement that *asṭurlāb* is a Greek word which was originally *asṭurlābūl* [read *asṭurlābūn*!],[54] meaning *dhāt al-nujūm*, "possessing stars" and that the letters after the b were removed "to make (the word) lighter", that is, "to make it easier to pronounce".

14 Mūsa ibn Ibrāhīm

Yet another etymology is contained in a treatise on the astrolabe attributed to Mūsa ibn Ibrāhīm, on whom I have no further information. The treatise is contained in MS New York Columbia 285,1 (fols. 1v-8r, *ca.* 1000 H), and begins "*ʾ-s-t-ṭ-l-ʾ-b* [*sic*!] in Greek means taking the altitude of a star because *ʾsṭr* is star in that language and taking is *lāb*.[55] Some people say that it means "balance of the stars". It is attributed to Ptolemy".

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[50] On Ibn Khallikān see the EI_2 article by Johannes Fück. This passage is found in his *Wafāyāt al-aʿyān*, II, pp. 184-185, transl. de Slane, III, pp. 581-582.

[51] On Sharaf al-Dīn al-Ṭūsī see the *DSB* article by Rushdi Rashed. On the linear astrolabe see **X-5.6** and the bibliography there cited.

[52] On Kamāl al-Dīn ibn Yūnus see Suter, *MAA*, no. 354, and Brockelmann, *GAL*, SI, p. 859.

[53] See *Cairo ENL Survey*, no. F70.

[54] There is a possibility that a Spanish influence is operating here to provide an ending *-ol*.

[55] The manuscript has *lāt* rather than *lāb*, which is probably an error of the copyist rather than the author. The former is at least attested in Egyptian Arabic: when I once complained about a bottle of Stella in a Cairo restaurant, the waiter asked me "*Fīh lāt*?".

15 Ibn Jamāʿa

Ibn Jamāʿa was a scholar of Hama in the late 13th century[56] and in the first chapter of his work on the use of the astrolabe he states that *asṭurlāb* is a foreign word meaning "measurer of the stars" or "balance of the sun", or according to another opinion, *asṭurlāqūn*, "mirror of the stars", taking *asṭur* as "star" and *lāqūn* as "mirror". Here perhaps *lāfūn* is intended: see the remarks on Ḥājjī Khalīfa (**27**). Ibn Jamāʿa adds that the derivation from *asṭur* and *Lāb* is not to be relied upon.

16 Abū ʿAlī al-Fārisī

Two etymologies for *asṭurlāb* are proposed by Abū ʿAlī al-Fārisī (*fl*. Hama, *ca*. 1300) in his treatise on the astrolabe entitled *Maqāṣid dhawi 'l-albāb* ... .[57] al-Fārisī first states that the name is a compound Greek word, *usṭur* (the text is vowelled) meaning "sun" and *lāb* meaning "balance", or, according to others "mirror", and then states that "the Arabs" say that *asṭur* is the plural of *saṭr*, "line", and that *Lāb* is the son of Idrīs.

17 al-Nuwayrī

al-Nuwayrī (d. 1332 in Tripoli),[58] in his encyclopaedia *Nihāyat al-arab fī funūn al-adab*, states that *asṭurlāb*, as well as the terms *ṭarjahāra* and *binkām* for water- and sand-clocks, were not Arabic.[59] This statement is also recorded by al-Khafājī (**26**).

18 al-Mizzī

Shams al-Dīn al-Mizzī, a leading astronomer in Damascus in the mid 14th century, wrote a treatise on the use of the astrolabe.[60] In the introduction he states that the word *asṭurlāb* is Greek and that it means "balance of/for the sun". See also the **addenda** at the end of this study.

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[56] On Ibn Jamāʿa see Brockelmann, *GAL*, II, pp. 89-90, and SII, pp. 80-81; Awwad, "Astrolabe Treatises" (in Arabic), no. 179; and *Cairo ENL Survey*, no. C23. On his family see the article "Ibn Djamāʿa" in EI_2 by K. S. Salibi. I have used the unique copy MS Cairo Muṣṭafā Fāḍil *mīqāt turkī* 6,1 (fols. 1v-20r, copied *ca*. 1150 H) of his work on the astrolabe.

[57] Abū ʿAlī al-Fārisī is not listed in the modern bio-bibliographic sources on Islamic science, except for Awwad, "Astrolabe Treatises" (in Arabic), no. 175, and *Cairo ENL Survey*, no. C20. His treatise is extant in the unique copy MS Cairo Qawala *mīqāt* 2,1 (fols. 1r-57v, copied *ca*. 800 H).

[58] On al-Nuwayrī see Brockelmann, *GAL*, II, p. 175, and SII, pp. 173-174, and the EI_2 article by M. Chapoutot-Remadi.

[59] Quoted in Lane, *Arabic-English Lexicon*, I, p. 58, from the commentary on the *Nihāyat al-arab* by Muḥammad ibn al-Ṭayyib al-Fāsī (Brockelmann, *GAL*, II, p. 175, and SII, p. 175). I have been unable to locate any reference to *asṭurlāb* in the published text of the *Nihāyat al-arab*.

[60] On al-Mizzī see *Cairo ENL Survey*, no. C34, and the references there cited, also **II-9.2**. I have used MS Istanbul Fatih 5397,25 of his treatise on the astrolabe.

19 Anonymous

The author of a treatise on the astrolabe in 14 *bāb*s entitled *Tuḥfat al-ṭullāb fī ʻl-ʿamal bi-ʼl-asṭurlāb*, which is probably a 14th- or 15th-century Egyptian or Syrian compilation, discussed the etymology of *asṭurlāb* in the introduction to his treatise.[61] He states that the name *asṭurlāb* is Greek and means "balance of the sun", and also that *Lāb* was a wise man who drew the lines (*asṭur*), so that the instrument was called *asṭur-Lāb*. This passage is related to the parallel one in the treatise of al-Mizzī (**18**). See also the **addenda**.

20 Sharaf al-Dīn al-Khalīlī

Sharaf al-Dīn al-Khalīlī, the nephew of the celebrated astronomer of mid-14th-century Damascus, Shams al-Dīn al-Khalīlī, wrote treatises on the standard instruments of his time, including one of the use of the astrolabe.[62] In the introduction to this he states that *asṭurlāb* is a foreign word meaning "(instrument for) measuring the stars" or alternatively "balance" or "mirror of the stars".

21 Anonymous

The anonymous author of a treatise in 25 *bāb*s on the spherical astrolabe which was probably another 14th-century Syrian compilation,[63] states that *asṭurlāb* is a foreign word to be explained as "mirror of the stars" or as "the balance of the sun".

22 al-Damīrī

The late-14th-century Egyptian scholar al-Damīrī is celebrated for his encyclopaedia on zoology and folklore entitled *Ḥayāt al-ḥayawān*.[64] In this work al-Damīrī apparently states that *asṭurlāb* means "balance of the sun" because *asṭur* means "balance" and *lāb* means "sun" in Greek. al-Damīrī's etymology was cited by Muḥammad al-Bannānī (**31**), but I have been unable to locate the reference to *asṭurlāb* in the published text of his encyclopaedia.

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[61] I have examined MS Istanbul Fatih 5397,24 (fols. 190r-195v, cop. 1113 H) of this work. Awwad listed several manuscripts of what he thought to be copies of a work with this title and attributed the treatise to the Andalusī astronomer Abū ʻl-Qāsim Aḥmad ibn ʿAbdallāh ibn Muḥammad al-Ṣaffār, but the listings and attributions are confused (*cf*. Awwad, "Astrolabe Treatises" (in Arabic), nos. 28 and 29). MS Princeton Garrett 1024 appears to be a copy of the same work as contained in the Fatih manuscript, and is likewise anonymous. The other manuscripts listed by Awwad are copies of a different treatise by Ibn al-Ṣaffār which has been published (see the article "Ibn al-Ṣaffār" by B. R. Goldstein in EI_2).

[62] On Sharaf al-Dīn al-Khalīlī see *Cairo ENL Survey*, no. C38, and the references there cited. I have used MS Istanbul Fatih 5397, fols. 65v-71r, of this treatise.

[63] This treatise is extant in MS Istanbul Hamidiye 1453, fols. 213v-219r, copied in 869 H.

[64] On al-Damīrī see the article in EI_2 by L. Kopf.

23 al-Fīrūzābādī

The celebrated philologist al-Fīrūzābādī (b. 1329 Shiraz, d. 1415 in Zabid) included an entry on *lāb* in his lexicon entitled *al-Qāmūs al-muḥīṭ*.[65] He states that *Lāb* was a man who drew lines and based calculations upon them and that the lines were called *asṭur-Lābin*, "the lines of *Lāb*". This became a compund word and the annexation construction was dropped. With the definite article the name became *al-asṭurlāb*, or *al-aṣṭurlāb* with a *ṣād* because of the *ṭā*ʾ. This etymology from the *Qāmūs* is also found in an astronomical manuscript copied in Amud about the year 1610 (see **10**).

24 al-Birjandī

There is no reference to the origins of *asṭurlāb* in the treatise on the astrolabe by the celebrated 13th-century Persian scholar Naṣīr al-Dīn al-Ṭūsī. However, in the Persian commentary on this treatise by ʿAlī al-Birjandī (*fl. ca*. 1500),[66] there is a section in which the author quotes the opinions of Kūshyār (**5**), al-Bīrūnī (**7**), and through him Ḥamza al-Iṣfahānī (not named) (**6**), as well as the anonymous commentator on the *Maqāmāt* of al-Ḥarīrī (**10**) and through him Abū Naṣr al-Qummī (**2**).[67] In this quotation the answer to the question asked by Hermes—not Idrīs—is either due to *Lāb* or Hermes himself: the Persian is ambiguous. al-Birjandī also mentioned that some people had said that *asṭur* means *taṣnīf*, "a written work or compilation" or "the act of preparing this", and that *Lāb*, a son of Hermes, had invented the instrument. al-Birjandī was later quoted by Munajjimak (**28**) and Isḥāq al-Zarkānī (**29**).

25 Jalāl al-Dīn al-Suyūṭī

MS London B.L. Add. 9599, fol. 7r, contains a note on the Arabic words *al-Mijisṭī* and *asṭurlāb* stated to be taken from *al-Nafḥa al-miskiyya*, a work by the late-15th-century Egyptian polymath Jalāl al-Dīn al-Suyūṭī.[68] The author states that Ptolemy was the first person to make an astrolabe. He adds that Kūshyār had said that the term *asṭurlāb* was Greek and that it meant "balance of the sun", and that some had said that *Lāb* was the name of the sun in Greek.

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[65] On al-Fīrūzābādī see the article by H. Fleisch in EI_2. I have examined MS Cairo Dār al-Kutub *lugha* 34 of his work, transcribed in 899 H from the author's copy. The entry on *asṭurlāb* in Lane's *Arabic-English Lexicon* (see n. 84) is based mainly on al-Fīrūzābādī.

[66] On al-Birjandī see Suter, *MAA*, no. 456; Storey, *PL*, II:1, pp. 54 and 80-82; and *Cairo ENL Survey*, no. G58.

[67] The Persian text edited in the Appendix was kindly prepared by Professor E. S. Kennedy.

[68] On al-Suyūṭī see Brockelmann, *GAL*, II, pp. 180-204, and SII, pp. 178-194, and the EI_2 article by E. Geoffrpy. On the treatise *al-Nafḥa al-miskiyya* see *GAL*, II, p. 202 (no. 291) and SII, p.197.

26 al-Khafājī

The celebrated Egyptian philologist Shihāb al-Dīn al-Khafājī (d. 1659) in his book on loan-words in Arabic entitled *Shifāʾ al-ghalīl* ... , gives no information on *aṣṭurlāb* other than that it, along with the terms *ṭarjahāra* and *binkām*, is not Arabic.[69] He adds that the word is mentioned in the *Nihāyat al-arab*, a work by al-Nuwayrī (**17**), and in fact al-Khafājī's remark is taken directly from al-Nuwayrī.

27 Ḥājjī Khalīfa

The 17th-century Turkish scholar Ḥājjī Khalīfa[70] in his bibliographical encyclopaedia *Kashf al-ẓunūn* records various interpretations of the name *asṭurlāb*.[71] He quotes Kūshyār (**5**) and al-Bīrūnī (**7**) without mentioning their names, and also the *Mafātīḥ al-ʿulūm* (**3**). When quoting al-Bīrūnī, Ḥājjī Khalīfa presents the name as *aṣṭurlāfūn*, perhaps reflecting a contemporary Greek pronunciation of β.[72] He concludes the passage on the astrolabe with the statement that the first person to make an astrolabe was Ptolemy and that the first person in Islam to make one was Ibrāhīm ibn Ḥabīb al-Fazārī. He then cites the titles of three books on the astrolabe (*Tuḥfat al-nāẓir*, *Bahjat al-afkār*, and *Ḍiyāʾ al-ʿuyūn*, none of which is extant, and none of which can be attributed to any author.

28 Munajjimak

Muḥammad Fazāʾī (?), known as Munajjimak (= the little astronomer), was chief astronomer in Istanbul about 1675, and wrote an extensive treatise on instruments of which only fragments survive.[73] The fifth *maqāla* of Munajjimak's treatise deals with regular planispheric astrolabes, universal astrolabes, and quadrants, and begins with a discussion of the word *asṭurlāb*. Munajjimak's remarks appear to be based on those of al-Birjandī (**24**), but in the story attributed to Abū Naṣr al-Qummī (**2**) it is no longer clear whether Hermes or *Lāb* is answering the question who drew the lines. Having been translated from Arabic to Persian and back to Arabic, the anecdote is now hopelessly confused. See also the next entry.

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[69] On al-Khafājī see Brockelmann, *GAL*, II, pp. 368-369, and SII, p. 396, and the EI_2 article by F. Krenkow, reprinted from EI_1. I have consulted MS Cairo Muṣṭafā Fāḍil *lugha* 20, in which *aṣṭurlāb* is mentioned on fol. 75v. Brockelmann lists only the Cairo manuscript, which may have been the basis for the two printed editions that he mentions.

[70] See the article "Kātib Chelebī" in EI_2 by O. S. Gökyay.

[71] Ḥājjī Khalīfa, *Kashf al-ẓunūn*, I, cols. 106-107.

[72] The 1892 Cairo edition of Ḥājjī Khalīfa's work has *asṭūrlāqūn*.

[73] Munajjimak is listed in *Cairo ENL Survey*, no. H23, and now Rosenfeld & İhsanoğlu, *MAIC*, p. 408, no. 1354, alas listing no new manuscripts. The text of the passage is found in MSS Cairo Dār al-Kutub *mīqāt* 735 and 70, which are two fragments of the fifth *maqāla* of his treatise.

29 Isḥāq al-Zarkānī

In some marginalia to an anonymous Arabic treatise on the astrolabe in 15 *faṣl*s, an individual named Isḥāq al-Zarkānī,[74] on whom I have no further information, translated the remarks of al-Birjandī (**24**), and introduced some minor modifications. For example, he said that the meaning of the Greek *asṭurlāfūn* (which is written *asṭurlānūn* in each of the copies I have consulted) was *mirʾāt al-kawākib*, "mirror of the stars", and that some had said *wāḥid al-kawākib*, implying that the term meant "mirror of the star". Here, however, *wāḥid* must result from a corruption of *akhdh*, or *wa-akhdh*.

30 ʿAbd al-Raḥmān al-Fāsī

The 17th-century Moroccan scholar ʿAbd al-Raḥmān al-Fāsī compiled a lengthy poem called *al-Uqnūm* on the different branches of knowledge, which included a section on the astrolabe.[75] In the margin of the Cairo manuscript of this work is a note on the orthography of *asṭurlāb* and *Baṭlaymūs* (= Ptolemy),[76] as well as a remark that Ptolemy was the first person to make the astrolabe, and a reference to the existence of a curious story about his invention of the instrument. The details of this story are preserved in a commentary on al-Fāsī's section on the astrolabe: see the next section.

31 Muḥammad al-Bannānī

Muḥammad ibn ʿAbd al-Salām ibn Ḥamdūn al-Bannānī, a scholar of Fez who died in 1163 H [= 1750], wrote an extensive commentary on al-Fāsī's poem (**30**) which is extant in MS Cairo Taymūr *riyāḍa* 113 (144 pp., copied 1327 H).[77] In a discussion of the etymology of *asṭurlāb*, the author first mentions that it is a foreign word meaning *miqyās al-nujūm*, "instrument for measuring the stars," or *mīzān al-nujūm*, "balance of the stars". He adds that "it is said that" firstly *lāb* is the name of the celestial sphere in Greek, and secondly that *Lāb* is the name of the inventor of the instrument and that it was originally *li-Ab*, "to the Father", where *Ab* was the name of "the Teacher", that is, Idrīs. Since *asṭur* is the plural of *saṭr*, *asṭurlāb* are "the lines of the sphere" (*asṭur al-falak*) and "lines of the philosopher" (*asṭur al-ḥakīm*). Muḥammad Bannānī concludes with a story about the invention of the astrolabe by Ptolemy,

[74] The treatise exists in numerous copies, many of which include the marginalia. I have used MSS Cairo Ṭalʿat *mīqāt* 154, Zakiyya 782, and K (= *falak*) 3844. See *Cairo ENL Survey*, nos. X24 and Z29.

[75] On ʿAbd al-Raḥmān al-Fāsī see Renaud, "Additions à Suter", no. 541; Brockelmann, *GAL*, II, pp. 612 and 675, and SII, pp. 694-695; *Cairo ENL Survey*, no. F50; and the article "ʿAbd al-Raḥmān al-Fāsī" by E. Levi Provençal in *EI*$_2$. I have used MS Cairo Dār al-Kutub J 3664 (287 fols., copied *ca*. 1250 H), fol. 179v.

[76] Ptolemy's name in Arabic was more often written Baṭlamiyūs, but in late texts both forms occur. *Cf.* the article "Baṭlamiyūs" in *EI*$_2$ by M. Plessner.

[77] On Muḥammad al-Bannānī see Brockelmann, *GAL*, II, p. 615 (where the Alexandria manuscript is mentioned) and *Cairo ENL Survey*, no. F57 (on the Cairo manuscript), and Rosenfeld & İhsanoğlu, *MAIC*, p. 409, no. 1361.

which was related by "a group of historians". This story is none other than the one related by Ibn Khallikān (**12**), and Muḥammad al-Bannānī's treatise is the only medieval *scientific* work known to me that contains this delightful story.

In a shorter commentary by Muḥammad al-Bannānī on the same poem, extant in MS Alexandria Baladiyya 3504 J (copied 1186 H), the author quotes the opinion of al-Damīrī (**22**) on *asṭurlāb*, and adds that:

> "Ptolemy was the first person to make an astrolabe and there is a strange story about his making it which we have related in the (longer) commentary".

32 Ibrāhīm Farūqī

There is a group of explanations of the term *asṭurlāb* in Persian, some of which clearly represent traditions quite different from those that I have documented in the Arabic sources. For example, in MS Cairo Ṭalʿat *mīqāt* 255, fol. 2v, copied *ca*. 1700—see **Fig. 1**—there is a note in Persian (alongside the Arabic note discussed in **10** above)[78] containing legends about Alexander and is stated to be taken from a work entitled *Sharaf-namā* by Ibrāhīm Fārūqī. I have been unable to identify the author, or to determine the relation of the work to the medieval Islamic folklore on Alexander.[79] The text translates as follows:

> "A first story: Alexander commanded all the sages to construct something so that it would remain in the world as a memorial to him. So Aristotle constructed an astrolabe which elucidated the secrets of the spheres for all the sages. It is the balance of the sun, which is called in Greece *asṭar-tarāzū* or *lāb-i aftāb*. Some said that *Lāb* is the name of another sage who by the request of Alexander constructed the astrolabe. Another opinion is that *Lāb* is the name of the son of Aristotle who is the constructor of the astrolabe. According to the fourth story, *Lāb* is the name of a son of Idrīs—blessings and praise be upon him—who had the greatest skill in the knowledge of science, and he made the astrolabe with the greatest excellence. But the first story is the most correct. It is also called *aṣṭurlāb* and *sṭrulāb* and *ṣṭurlāb* and *ṣulāb*. Taken from the *Sharaf-nāma* of Ibrāhīm Fārūqī."

Notice that the expression *tarāzū-yi aftāb* for "balance of *the sun*" is recorded by Muḥammad ibn Ayyūb Ṭabarī (**10***). However, *lāb-i aftāb* is new, and would not mean "balance of the stars". However, *lab-i astar*, meaning "lip(s) of the star(s)", appears to have been in circulation in Persian-speaking circles, at least in the 17th century (see **33**).

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[78] I found this Persian text whilst preparing the illustrations for the *Cairo ENL Survey*: see pl. LIII on p. 273 and the caption on p. 207. I am grateful to Professor E. S. Kennedy, and also to Professor Peter Chelkowski of New York University, for reading and translating this text.

[79] On the Alexander legends in general see the EI_2 article "Iskandarnāma" by A. Abel. Ibrāhīm al-Fārūqī is not mentioned in Storey, *PL*, and no such references to Aristotle and the astrolabe are contained in such basic works on the medieval Iskandar as Southgate, *Iskandarnamah*, and Cary, *The Medieval Alexander*. The astrolabe is mentioned in the *Iskandarnāmeh* of Niẓāmī (*ca*. 1175): in a decisive battle against the Russians, Iskandar is guided by calculations made with an astrolabe. See further Chelkowski, "Nizāmī's *Iskandarnāmeh*", p. 38, and **Fig. X-1.2**.

33 Jean Chardin

The 17th-century French traveller Jean Chardin spent time with the astrolabists of Isfahan and he has left us a description of the methods they used to construct astrolabes.[80] His account is of considerable interest for the history of Islamic instrumentation, and it also contains an account of the opinions of the Persian astronomers on the meaning of the word *asṭurlāb*:

> Je viens à l'Astrolabe, & je dirai d'abord que ce nom vient d'Asterleb, terme Persan, qui veut dire lèvres des Etoiles; parce que c'est par cet Instrument que les Etoiles se font entendre. D'autres disent, qu'il faut prononcer Astir lab, c'est à dire, connaissance des Etoiles, & c'est comme les Persans apellent d'ordinaire cet Instrument-là; mais dans leurs livres & dans leurs leçons ils l'apellent Veza Kouré, mot abrégé de Veza el Kouré, qui signifie position de la Sphère, parce que cet Instrument & la projection des cercles de la Sphère est un plan. C'est sans doute de ce terme Veza el Kouré qu'est venu le terme barbare de Valzagore, qui se trouve dans Regiomontanus, & dans les auteurs qui l'ont devancé, pour signifier l'Astrolabe.

These interpretations of *asterleb* as a Persian word meaning "lips of the stars", and that the word should be pronounced *astir lab* and means "knowledge of the stars", have no counterpart in the known Islamic textual sources. However, *lab* does mean lip in Persian, cognate to *labium* in Latin.[81]

Chardin's report that the Persians "in their books and in their lessons" call the instrument *veza el kouré* is of considerable interest. What he meant is that "it is reported that they call it this", for he certainly did not hear this from any Iranian instrument makers. The expression looks as though it derives from *waḍʿ al-kura*, "placing the sphere". But no Arabic astrolabe texts have this (meaningless) expression, and, as Paul Kunitzsch has shown, the numerous Latin variant forms of *walzagora* result from a medieval European corruption of the expression *basṭ al-kura*, "the flattening of the sphere", attested in the textual tradition of Maslama al-Majrīṭī.[82]

34 Aḥmad Bāshā Mukhtār

In a text-book on traditional mathematical astronomical instruments called *Riyāḍ al-Mukhtār* and published in both Turkish and Arabic in the 1880s, the author al-Ghāzī Aḥmad Bāshā Mukhtār states that *asṭurlāb* is derived from two Latin words: *asṭur* meaning "star or celestial body" and *labiyūm* meaning "plate" (*lawḥa* or *ṣafīḥa*).[83] He also states that the astrolabe was invented by Ptolemy.

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[80] This passage has been studied in Michel, "Construction des astrolabes persans", esp. p. 485. On Chardin in Iran, see now King, *Mecca-Centre World-Maps*, p. 440.

[81] We find the same notion—*astrolabium quasi labium astri*—in early Latin texts: see Kunitzsch, "Fachausdrücke der Astrolabliteratur", p. 470, and the concluding remarks to this study.

[82] See Hartner, "The Astrolabe", A, p. 287, and Kunitzsch, "Mittelalterliche Glossare", pp. 20-21, *sub vuazalcora*, and *idem*, Fachausdrücke der Astrolabliteratur", pp. 63-64, *sub basṭ al-kura*, where "(Ober-)Fläche der Kugel" is to be corrected to the equivalent of "flattening the sphere". See also Dorn, "Drei arabische Instrumente", p. 83, Morley, *Astrolabe of Shāh Ḥusayn*, p. 5, and Gandz, "The Astrolabe in Jewish Literature", p. 476, where the term is mentioned as if it was of Arabic origin.

[83] Mukhtār, *Riyāḍ*, p. 238. I owe this reference to the kindness of Professor Paul Kunitzsch. In 2003, Professor Ekmeleddin Ihsanoğlu kindly sent me a photocopy of the Turkish version.

Concluding remarks

The extent to which such popular etymologies gained acceptance in informed Muslim circles is revealed in the entry for *lāb* in Steingass' *Persian-English Dictionary*, published in 1892.[84] He lists the following meanings:

> "the sun; request; supplication; name of the son of Idrīs; also of the inventor of the astrolabe; or of the son of a Greek King of the name of Istar (?)."

In the last proposal, *Istar* is probably a corruption of *asṭur*. With the identification of *Lāb* as the son of *Asṭur* we should consider bringing this survey of medieval Islamic notions about the origin of the Arabic term *asṭurlāb* to an end.

As already noted, a preliminary survey of the Latin sources was conducted by Paul Kunitzsch in 1981.[85] He found that both the notion *astrolabium quasi labium astri* in a 10th- or 11th-century text from Ripoll, and the notion *astrolabium est nomen grecum cuius interpretatio est acceptio stellarum* of Pseudo-Messahalla, were in circulation in medieval Europe. He further showed that the 16th-century German astronomer Johannes Stöffler knew of the correct etymology of Pseudo-Messahalla and even the nonsense about the *asṭur* of *Lāb*, which Stöffler had found in the Latin translation of the commentary of ʿAlī ibn Riḍwān (**4***).

Surely more attestations of these etymologies and perhaps even a few others will be found as more Arabic, Persian and Latin manuscripts of scientific and pseudo-scientific as well as lexicographical and encyclopaedic works are investigated.

The word "astrolabe" continues to excite, to mystify, and to confuse. A lady asked me at a cocktail party in the 1990s how my work on Skylab was progressing. But amongst the *conoscienti*, the fascination with the magic of the device continues. In the same spirit as our medieval authors, Francis Debeauvais and Paul-André Befort in 2002 entitled their beautiful new book *Cueillir les étoiles—Autour des astrolabes de Strasbourg*.

Addendum: In the texts of al-Mizzī (**18**) and an anonymous Mamluk astronomer (**19**) there is a statement that is taken from the treatise on the astrolabe by the Andalusī astronomer Abu 'l-Ṣalt *ca*. 1000, which was compiled whilst he was in prison in Egypt. The remark is to the effect that "the astrolabe is an instrument with which one can achieve the solution of many astronomical problems, for practical and didactic purposes, not including those relating to (the moon and) five planets, by the easiest procedures and simplest methods" (*huwa āla yatawaṣṣal bihā ilā maʿrifat kathīr min al-aʿmāl al-nujūmiyya al-taʿlīmiyya min ghayr al-khamsa al-mutaḥayyara bi-ashal ṭarīq wa-aqrab maʾkhadh*). This very sensible remark is indeed found in Abu 'l-Ṣalt's treatise (MS London Or. 5479,1, *naskhī*, Egypt *ca*. 1200, fol. 2v). Alas, for our present purpose, neither he, nor his contemporary Ibn al-Samḥ (Viladrich, *Ibn al-Samḥ on the Astrolabe*), mentions the origin of the astrolabe or the etymology of its name. The influence of the treatise of Abu 'l-Ṣalt in the Islamic East and West merits further investigation.

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[84] Steingass, *Persian-English Dictionary*, p. 1110. The article on *asṭurlāb* in Edward Lane's *Arabic-English Lexicon*, published in 1863, is based on the remarks of al-Nuwayrī (**17**) and al-Fīrūzābādī (**23**): *cf.* Lane, *Arabic-English Lexicon*, I, p. 58, cited in Gunther, Astrolabes, I, p. 111, and Gandz, "The Astrolabe in Jewish Literature", p. 475.

[85] Kunitzsch, "Fachausdrücke der Astrolabliteratur" (see n. 9 above), pp. 470-471.

ARABIC TEXTS

(١) قطعة من كتاب العمل بالأصطرلاب المنسوب خطأً إلى ما شاء الله

مترجمة من النصّ اللاتيني

... [أصطرلاب اسم يوناني معناه أخذ الكواكب] ...

(٢) قطعة من كتاب المدخل إلى علم النجوم لأبي نصر القمي

المصادر: أ) مخطوطة دار الكتب المصرية طلعت ميقات ٢٢٢، ق ١١٥و – ١١٥ظ
ب) مخطوطة استانبول فاتح ٤٣٢٧، ق ٤٤ و

... الفصل الثاني من المقالة الثالثة في ذكر الأصطرلاب [1] واسم كل قطعة منه [2] وما فيه من الخطوط والمقنطرات والدوائر والأقسام كان العلماء الأولون أخذوا [3] كرة على مثال الفلك تتحرك على قطبين وركبوا عليها عنكبوتاً عليه [4] منطقة فلك البروج وعلى الكرة الدوائر العظام مثال دوائر الارتفاع ودوائر الأفق ودوائر نصف النهار ودائرة [5] معدل النهار وغيرها من الدوائر وكانوا يقيسون [6] بها النهار والليل ويصححون [7] بها الطالع إلى أيام إدريس النبي [8] عليه السلام وكان لإدريس ابن يقال له لاب وله [9] علم جليل ومعرفة حسنة [9] في هيئة [10] الفلك فبسط الكرة واتخذ هذا الأسطرلاب الذي في إيدي الناس وأنفذه إلى أبيه إدريس فأخذه [11] إدريس وتأمله [11] وقال هذا من سطره [12] فقيل [13] له هذا أسطرلاب [13] فوقع عليه هذا الاسم واستعمله [14] الناس من بعده [15] وللأسطرلاب قطاع [15] كثيرة أنا أذكرها هنا اسم [16] كل قطعة منها ...

[1] في ب: الأسطرلاب . [2] في أ: منها . [3] في ب: اتخذوا . [4] في ب: عليها . [5] في ب: دواير . [6] في أ: يقيسوا، في ب: يقسموا . [7] في أ: ويصححوا، في ب: ويصحون . [8] ناقص في أ . [9-9] في ب: معرفة حسنة . [10] في ب: هية . [11-11] في ب: وتامله إدريس . [12] في أ: اسطره . [13-13] في أ: سطره لاب . [14] في أ و ب: واستعملوه . [15-15] في ب: وايضاً يقال ان الاسطر بلسان الروم هو الميزان واللاب الشمس فسموه أسطرلاب اي ميزان الشمس والأسطرلاب [كذا] اقطاع . [16] ناقص في أ .

(٣) قطعة من مفاتيح العلوم لأبي عبد الله الخوارزمي

المصدر: النصّ المطبوع (القاهرة ،١٣٤٢ هـ) ، ص ١٣٤

... الأصطرّلاب معناه مقياس النجوم وهو باليونانية أصطرلابون وأصطر هو النجم ولابون هو المرآة ومن ذلك قيل لعلم النجوم أصطرنوميا وقد يهذي بعض المولعين بالاشتقاقات في هذا الاسم بما لا معنى له وهو أنهم يزعمون أن لاب اسم رجل وأسطر جمع سطر وهو الخط وهذا اسم يوناني اشتقاقه من لسان العرب جهل وسخف ...

(٤) قطع من كتاب الفهرست لابن النديم

المصدر: النصّ المطبوع (١٨٧١ م)

ص ٢٧٠: أبيون البطريق وأحسبه قبل الإسلام بيسير أو بعده بيسير وله من الكتب كتاب العمل بالأسطرلاب المسطح ...

ص ٢٧٣: الفزاري ... وهو أول من عمل في الإسلام أسطرلابا وعمل مبطحاً ومسطحاً وله من الكتب ... كتاب العمل بالأسطرلاب وهو ذات الحلق كتاب العمل بالأسطرلاب المسطح ...

ص ٢٨٤: الكلام على الآلات وصناعها كانت الأسطرلابات في القديم مسطحة وأول من عملها بطلميوس وقيل عملت قبله وهذا لا يدرك بالتحقيق وأول من سطح الأسطرلاب ابيون البطريق وكانت الآلات تعمل بمدينة حران ومن ثم تشتتت وظهرت ولكنها زادت واتسع للصناع العمل في الدولة العباسية منذ أيام المأمون إلى وقتنا هذا فإن المأمون لما أراد الرصد تقدم إلى ابن خلف المروروذي فعمل له ذات الحلق وهي بعينها عند بعض علماء بلدنا هذا وقد عمل المروروذي الأسطرلاب ...

قطعة من كتاب تاريخ الحكماء لابن القفطي

المصدر: النصّ المطبوع (ليبزيج ، ١٩٠٣)، ص ٧١

انبون البطريق حكيم رياضي مهندس عالم بصناعة الآلات الفلكية كان في حدود مبدأ الإسلام قبله أو بعده فمن تصنيفه كتاب العمل بالأسطرلاب المسطح ...

(٥) قطعة من مقدمة كتاب الأصطرلاب لكوشيار بن لبّان

المصدر: مخطوطة باريس المكتبة الوطنية عربي ٢٤٨٧

... الأسطرلاب كلمة يونانية وأشهر ما قيل في معناه ميزان الشمس ...

(٦) قطعة من كتاب الموازنة لحمزة الإصفهاني

انظر ٧ ادناه

(٧) قطعة من كتاب التفهيم لصناعة التنجيم لأبي الريحان البيروني

المصدر: مخطوطة لندن المكتبة البريطانية ٨٣٤٩ (كما طبعت في النصّ المطبوع، لندن، ١٩٣٤ م، ص ١٩٤)

ما أصطرلاب هو آلة لليونانيين اسمها أصطرلابون أي مرآة النجوم ولهذا خرج له حمزة الاصفهاني من الفارسية أنه ستاره ياب [1] ...

[1] في الأصل: بشاره باب .

قطعة في معنى الأسطرلاب من إفراد المقال في أمر الظلال للبيروني

المصدر: النصّ المطبوع (حيدراباد، ١٩٤٨ م)، ص ٦٩، مع تصليحات كنيدي في ترجمته (حلب، ١٩٧٦ م)، ص ١١١

... قد ذكر حمزة الإصفهاني في كتاب الموازنة أن الأسطرلاب لفظة فارسية قد عرّبت فإنها ستاره [1] ياب أي مدرك النجوم وممكن أن يكون هذا اسمه عند الفرس إما مشتقا من الفعل الخاص به وإما معرّباً من اليونانية كتعريب الفارسية فإن اسمه باليونانية أسطرلابون [2] وأسطر هو النجم بدليل أن علم الهيئة يسمي عندهم أسطرونوميا وصناعة أحكام النجوم أسطرولوجيا [3] وهو آلة وجدنا لهم في صنعتها والعمل بها كتبا قديمة ولم نجد لغيرهم فيها شيئاً وإن كان عندهم منقولا منهم وأهل المشرق لا يعرفون الأسطرلاب ولا يهتدون لغير استعمال الظل بدله ...

[1] في النصّ المطبوع: اشتاره . [2] في النصّ المطبوع: أسطرليون . [3] في النصّ المطبوع: أسطرلوخيا .

قطعة من مقدمة رسالة في استعمال الأسطرلاب للبيروني

المصدر: مخطوطة باريس المكتبة الوطنية عربي ٢٤٩٨، ١، ق ١ ظ – ٢و

... وما عثرنا لأحد من القدماء على كتاب في استعمال الأسطرلاب غير كتاب [1] ابيون البطريق [1] في العمل في الأسطرلاب المسطح إفرازا له في التنقيب عن الأسطرلاب الكري واشتمل كتابه هذا على مائة وسبعة وخمسين باباً إذا حصلت بالتهذيب ونقحت عن زوائد التقريب نقصت عدتها شيئاً كثيراً على أن أبوابه في الكتاب ناقصة عما يضمنه الفهرست من الأعداد وأعماله في بعضها ميسرة لقصور الترجمة عنها وفساد الأصل المنقول وثابت بن قرة إما أنه تولى الترجمة وإما أنه أصلح منه ما أمكن عند المطالعة ...

[1-1] في الأصل: اهون الطريق [!!] .

(٨) قطعة من أول مقدمة المقياس المرجّح في العمل بالأسطرلاب المنسوب إلى أبي ريحان البيروني

المصدر: مخطوطة دار الكتب المصرية طلعت ميقات ١٥٥، ١، ق ١ ظ – ٢ ظ

بسم الله الرحمن الرحيم وبه نستعين المقياس المرجّح في العمل بالأسطرلاب المسطح وهو مقدمة ومقالتان وكل اسم [1] السين فيه أصل وفيه طاء كالصراط والأصطرلاب أو خاء كممخرات أو عين كمسعنة أو قاف كصندوق فإنه يجوز فيه السين والصاد والأصطرلاب اسم عجمي واستشقاق [2] معناه من العربية بعيد وذكر أبو الحسن ثابت بن قرة في العمل بالأسطرلاب له أن إبرخس وهو قبل بطلميوس وضع الأسطرلاب وسطحه على مثل ما وضعه لاب بعد أن كان كريّا وإن الذي دعاه إلى ذلك أنه رأي الكرة [3] كثيراً عناؤها قليلاً نفعها [3] فأراد أن يضع آلة قريبة يسيرة جامعة لكثير من الأعمال يوضح بها ما غمض في الآلة المقبّبة الكرية وذكر أنه كان من عادة الحكماء إذا [4] أرادوا [5] وضع كتاب أن يضعوه على وجهين أحدهما أن يضعوه بالغامض

في العلم والرمز في القول الذي لا يدركه إلا من أحكم أمر الفلسفة وعلا فيها والثاني أن يضعوه بالكشف والبيان إرادة لشرحه وبسطه وإظهار علله وذكر أن الأسطرلاب محدود بثلاثة حدود لا يكون إلا منها الأرثماطيقي وهو معرفة حساب الأعداد وخواصّها والثاني معرفة الهندسة وهي المسح بالقسي والأوتار المثلثة والمربّعة إلى المعشرة والمناسبات وما جرى مجراها والأسطرنوميا [6] وهو معرفة ما يشتمل عليه الزيجات من معرفة حركات الكواكب بمراكز تداويرها وأركانها واختلاف صعودها وهبوطها ورجوعها واستقامتها وإبطائها وسرعتها في سيرها وأخذها في العرض وغير ذلك مما يشتمل عليه الزيجات قال وهذا كله معروف موجود في الأصطرلاب ويسمى ذات الصفائح لاشتماله عليها وذكر أن علة تسطيح إبرخس للمسطح هو أن الفلك المستوي المعبّر عنه بدائرة معدل النهار في الكرة وفي الأسطرلاب المسطح هو المشتمل على أجزاء الحجرة [7] من الأم والفلك المائل ما اشتمل من الكرة على البروج وأجزائها وفي الأسطرلاب المسطح هو منطقة فلك البروج من الشبكة والفلك المائل في الطبيعة مثل المستوي ولكن اختلاف أقطارها خالف بينهما ويميل مركز أحدهما عن مركز الاخر بقدر الميل الأعظم وهو في الكرة من جهة الشمال والجنوب فأراد إبرخس أن يصير [8] الميلين في جانب واحد واختار وضعه شمالياً لأنه الموضع العامر من الأرض فجمع المسطح ما في البيضة من الفلكين المستوي والمائل وقد قام البرهان الهندسي أنه لا يمكن أن يوجد أسطرلاب يؤدّي للأعمال الحسابية التعليمية على غير الوصفين الأصليين [9] الشمالي [10] والجنوبي وإن جميع الأوضاع على اختلافها لا تخرج عنها وإنما تختلف صور أجناسها من اختلاف التركيب من هذين الأصلين وسمّي كل من من الوضعين باسم جهة [11] القطب الظاهر في عرض الأسطرلاب ومقنطراته من دوائر موازية للأفق ونقطة سمت الرأس مركزها في الكرة وإنما اختلفت مراكزها في نوعي المسطح للمتسطح وحدبة [12] قوس الأفق الشمالي إلى ما يلي أسفل الأسطرلاب وأفق الجنوبي بالعكس ومقنطرات أحدهما يخالف أشكال المقنطرات الآخر لمقنطرة عرض الصفيحة في الجنوبي تكون خطاً مستقيماً ثم يعود وضع المقنطرات إلى خلاف وضع الأول [13] فتكون حدباتها إلى ما يلي الشمال عكس المقنطرات إلى خلاف الوضع الأول [13] فتكون [14] حدباتها إلى ما يلي الشمال عكس المقنطرات دون عرض البلد إلى [15] ...... [15] ومن جيد الكتب في تسطيح الكرة تسطيح الكرة لبطليموس والفرغاني وأحسنها استيعاب الوجوه الممكنة [16] في صنعة الأسطرلاب للشيخ الإمام أبي الريحان محمد بن أحمد البيروني [16] ...

[1] كلمة اسم مكررة في الأصل والثانية مشطوبة . [2] في الأصل: اشتقتاق . [3-3] هكذا في الأصل . [4] في الأصل: انهم ذا، مصلح إلى: إذا . [5] في الأصل: أرادو . [6] في الأصل: والأسطرلاب وبرميقا . [7] في الأصل: الكرة الحجرة، وكلمة الكرة مشطوبة . [8] في الأصل: يصر . [9] في الأصل: الأصلين . [10] في الأصل: الشمال . [11] هذه الكلمة غير واضعة في الأصل . [12] في الأصل: وحدبه . [13-13] في الأصل: مكرر ومشطوب . [14] في الأصل: فيكون . [15-15] في الأصل بياض . [16-16] في الأصل: للشيخ الامام ابي الريحان محمد بن احمد في صنعة الاسطرلاب البيروني [!] .

(٩) قطعة من رسالة في العمل بالأسطرلاب [لابن الزرقاله]

المصدر: مخطوطة استانبول ايا صوفيا ٢٦٧١، ق ١٣٣ ظ

... اعلم أن اسم الأسطرلاب لفظة يونانية ترجمتها أخذ الكواكب وذلك لأنه يؤخذ به [1] ما يطلب علمه من مواضع الكواكب ويذكر بطلميوس أنه كالكرة قد بسطت فصير مركزه [2] قطبها الظاهر ...

[1] في الأصل: ان . [2] في الأصل: مركز .

(١٠) فائدة في الأسطرلاب منقولة من شرح مقامات الحريري لشارح مجول

المصادر: أ) مخطوطة دار الكتب المصرية مصطفى فاضل هيئة ١، ق ١ و
ب) مخطوطة دار الكتب المصرية تيمور حكمة ١٥، ص ١٣٧

الأسطرلاب [1] مقياس النجوم والشمس يعني شيء [2] ينظر فيه ويعرف به [2] سير الكواكب والشمس وأول [3] من وضع [4] هذا الشيء لاب وهو اسم [5] ابن [6] إدريس [7] عليه السلام [7] فلما صنع هذا الشكل وجيء به إلى إدريس [8] عليه السلام [8] قال [9] من سطر هذه [10] الأسطر قيل له لاب فأضيف إلى لاب وقيل فارسي معرّب أصله بالفارسية [11] ستاره ياب [11] يعنى يظهر فيه [12] الكواكب [13] ويجوز قلب [13] السين صادا لمجاورة الطاء لتعرّب مخرجهما [14] [15] انتهى من شرح مقامات الحريري [15]

[1] في ب: أسطرلاب . [2-2] في ب: يعرف فيه . [3] في ب: أول . [4] في ب: صنع . [5] في ب: رسم . [6] في أ: لا بن . [7-7] في ب: ع م . [8-8] تاقص في ب . [9] في أ و ب: فقال . [10] في ب: هذا . [11-11] في أ: شاره ثاب، وفي ب: ستاره . [12] في أ: في . [13-13] في أ: وقلب . [14] في ب: مخرجاهما . [15-15] في أ: به (؟) شرح المقامات .

فائدة في الأسطرلاب يقال إنها منقولة من شرح مقامات الحريري للمطرّزي

المصدر: مخطوطة دار الكتب المصرية طلعت ميقات ٢٥٥، ق ٢ ظ

أسطرلاب كلمة يونانية ومعناه ميزان الشمس عن أبي الحسن وقال أبو ريحان هو آلة اليونانيين اسمها أصطرلابون أي مرآة [1] النجوم ولهذا خرج [له] [2] حمزة الإصبهاني من الفارسية أنه [3] ستاره ياب [3] وعن أبي نصر [4] أن العلماء الأولين كانوا اتخذوا [5] كرة على مثال الفلك يتحركت على قطبين عليها دوائر عظام كانوا يقيسون [6] بها الليل والنهار ويصححون بها الطالع إلى أيام إدريس [7] عليه السلام [7] وكان له ابن يقال له لاب له معرفة حسنة في هيئة [8] الفلك فبسط الكرة واتخذ هذا الأسطرلاب وأنفذه إلى أبيه فقال من سطره فقيل سطره لاب فوقع عليه هذا الاسم والأول أصحّ والأصل فيه السين والصاد أبدل منه لمكان الطاء مقدمة شرح مقامات الحريري لناصر [9] بن أبي المكارم بن علي المطرّزي.

[1] في الأصل: مرات . [2] ناقص في الأصل فانظر ملتقط رقم ٧ أعلاه . [3-3] في الأصل: ستارة باب . [4] في الأصل: عمر . [5] في الأصل: تخذوا . [6] في الأصل: يقسمون . [7-7] في الأصل: ع م . [8] في الأصل: هية (؟) . [9] في الأصل: ناصر .

(١٠أ) قطعة من شش فصل لمحمد بن أيّوب طبري

المصدر: محمد بن أيّوب طبري، شش فصل، ص ٧٧

معنى نام أسطرلاب چيست؟ اسمي است به زبان يوناني برونهاده ومعنيش ترازوى آفتاب است

(١١) قطعة من مقدمة الرسالة في عمل الأسطرلاب المسرطن لأبي نصر أحمد بن زرير

المصدر: مخطوطة ليدن ٥٩١، ق ٣٢ ظ

... إن الأسطرلاب كلمة يونانية وهي آلة شريفة وميزان الشمس تحوي على أكثر الأعمال النجومية بالقوة وكانت تحويها بالفعل لو أمكن أن تنقسم دوائرها إلى الدقائق والثواني ...

(١٢) قطعة من كتاب وفيات الأعيان لابن خلكان

المصدر: النصّ المطبوع (القاهرة بلا تاريخ)، المجلد الثاني، ص ١٨٤ ــ ١٨٥

أبو القاسم هبة الله بن الحسين ... المنعوت بالبديع الأسطرلابي الشاعر المشهور أحد الأدباء الفضلاء ... والأسطرلابي بفتح الهمزة وسكون السين المهملة وضمّ الطاء المهملة وبعدها راء ثم لام الألف ثم باء موحّدة هذه هي [1] النسبة إلى الأسطرلاب وهو الآلة المعروفة قال كوشيار بن لبان بن باشهري الجيلي صاحب كتاب الزيج في رسالته التي وضعها في علم الأسطرلاب إن الأسطرلاب كلمة يونانية معناها ميزان الشمس وسمعت بعض المشايخ يقول إن لاب اسم الشمس بلسان اليونان فكأنه قال أسطر الشمس اشارةً إلى الخطوط التي فيه وقيل إن أول من وضعه بطلميوس صاحب المجسطي وكان سبب وضعه له أنه كان معه كرة فلكية وهو راكب فسقطت منه فداستها دابته فخسفتها فبقيت على هيئة الأسطرلاب وكان أرباب علم الرياضة يعتقدون أن هذه الصورة لا ترسم إلا في جسم كري على هيئة الأفلاك فلما رآه بطلميوس على تلك الصورة علم أنه يرتسم في السطح ويكون نصف دائرة يحصل منه ما يحصل من الكرة فوضع الأسطرلاب ولم يسبق إليه وما اهتدى أحد من المتقدمين إلى أن هذا القدر يتأتي في الخط ولم يزل الأمر مستمرّاً على استعمال الكرة والأسطرلاب إلى أن استنبط الشيخ شرف الدين الطوسي المذكور في ترجمة الشيخ كمال الدين بن يونس رحمهما الله تعالى وهو شيخه في فن الرياضة أن يضع المقصود من الكرة والأسطرلاب في خط فوضعه وسماه العصا وعمل له رسالة بديعة وكان قد أخطأ في بعض هذا الوضع فأصلحه الشيخ كمال الدين المذكور وهذّبه ...

[1] ناقص في الأصل .

(١٣) قطعة من رسالة مغربية أو أندلسية مجهولة المؤلف

المصدر: مخطوطة دار الكتب المصرية ميقات ١١٦٩، ٦، ق ٤٥ و

... الأسطرلاب وهي كلمة يونانية وأصلها أسطرلابول [!] ومعنى الأمر ذات النجوم حذف ما بعد الباء للتخفيف ...

(١٤) قطعة من رسالة في الأسطرلاب لموسى بن إبراهيم

المصدر: مخطوطة نيويورك كولومبيا ٢٨٥، ١، ق ١ظ

... الأستطرلاب [!] ومعناه باليونانية أخذ ارتفاع الكوكب لأن اسطر في اللغة كوكب والأخذ لات [!] وقال بعض إن معناه ميزان الكوكب وهو منسوب إلى بطلميوس ...

(١٥) قطعة من ملخّص الألباب في العمل بالأسطرلاب لابن جماعة الكنّاني

المصدر: مخطوطة دار الكتب المصرية مصطفى فاضل ميقات تركي ٦، ١، ق ١ ظ

... الباب الأول معنى لفظ الأسطرلاب الأسطرلاب لفظ عجمي معناه باليونانية مقياس النجوم وقيل معناه ميزان الشمس ويجوز بالسين والصاد وقيل أصله الأسطرلافون [1] وأسطر هو النجم ولافون [2] هو المرآة ومعناه مرآة النجوم ثم عرّب فقيل أسطرلاب وأما قول بعضهم أن لاب اسم رجل وأسطر جمع سطر مضاف إليه [3] فلا يعتمد [3] عليه لأنه اسم أعجمي فاشتقاق معناه من العربية بعيد ...

[1] في الأصل: الأسطرلاقون (!) . [2] في الأصل: لاقون . [3-3] في الأصل: في لا يعرج .

(١٦) قطعة من مقدمة مقاصد ذوي الألباب في العلم بالعمل بالأصطرلاب لأبي على الفارسي

المصدر: مخطوطة دار الكتب المصرية قوله ميقات ٢، ١، ق ٢ ظ

... الفصل الأول في التسمية أسطرلاب اسم مركب يوناني فأسطر اسم للشمس ولاب اسم للميزان وقيل اسم المرآة فمعناه حينئذ ميزان الشمس أو مرآة الشمس إذ يجوّزون تقديم المضاف إليه على المضاف عند التلفظ بها وعن العرب أن أسطر يفتح الهمزة جمع سطر عملها لاب وهو ابن إدريس عليه السلام على هذه الآلة فصار مجموع الاسمين علماً على هذه الآلة ...

(١٧) قطعة من كتاب نهاية الأرب للنويري

انظر رقم ٢٦ أدناه

(١٨) قطعة من رسالة في العمل بالأسطرلاب للمزي

المصدر: مخطوطة استانبول فاتح ٢٥،٥٣٩٧، ق ١٩٥ ظ

... الأسطرلاب وهي لفظة يونانية فهم منها أنه ميزان للشمس وبالجملة هو آلة يتوصل بها إلى معرفة كثير من الأعمال النجومية التعليمية من غير الخمسة المتحيّرة بأسهل طريق وأقرب مأخذ ...

(١٩) قطعة من تحفة الطلاب في العمل بالأسطرلاب لمؤلف مجهول

المصدر: مخطوطة استانبول فاتح ٢٤،٥٣٩٧، ق ١٩٠ و

... أما الأسطرلاب فهي لفظة يونانية فهم منها أنه ميزان الشمس وأما لاب فهو رجل حكيم قد سطر هذه الأسطر فسمي بها أسطرلاب وبالجملة هو آلة يتوصل بها إلى معرفة كثير من الأعمال بأسهل طريق وأقرب مأخذ ...

(٢٠) قطعة من أول رسالة في العمل بالأسطرلاب لشرف الدين الخليلي

المصدر: مخطوطة استانبول فاتح ٥٣٩٧، ق ٦٥ ظ

... الأسطرلاب لفظ أعجمي معناه مقياس النجوم وقيل ميزانها أو مرآتها ...

(٢١) قطعة من رسالة في العمل بالأسطرلاب الأكري لمؤلف مجهول

المصدر: مخطوطة استانبول حامدية ١٤٥٣، ق ٢١٣ ظ

... الأسطرلاب لفظة أعجمية تفسيرها [1] مرآة النجوم وقيل ميزان الشمس ...

[1] في الأصل: تفسير .

(٢٢) قطعة من حياة الحيوان للدميري

انظر رقم ٣٢

(٢٣) فائدة عن لاب من القاموس المحيط لمجد الدين الفيروزابادي

المصادر: أ) مخطوطة دار الكتب المصرية لغة ٣٤، باب الباء، فصل اللام
ب) مخطوطة دار الكتب المصرية مصطفى فاضل هيئة ١، ق ١ و

... واللاب [1] اسم رجل [1] سطر أسطرا [2] وبنى عليها حساباً فقيل أسطرلاب ثم مزجا ونزعت الإضافة فقيل الأسطرلاب [3] معرفة والأصطرلاب لتقدم السين على الطاء ...

[1-1] في أ: بالنوبة (؟) ورجل . [2] في ب: سطرا . [3] في ب: الأسطر اللاب .

(٢٤) قطعة في الأسطرلاب من شرح علي البرجندي على رسالة بيست باب لنصير الدين الطوسي

المصادر: أ) مخطوطة دار الكتب المصرية طلعت مجاميع ٢،٣٩٨، ق ٤ ظ
ب) مخطوطة دار الكتب المصرية طلعت ميقات فارسي ٢،٢، ق ٣١ و
ج) مخطوطة دار الكتب المصرية س ٤٤٣٥، ق ٥ و

... لغت اصل اسطولاب بسين است وبعضى [1] انرا بصاد بدل كرده اند [2] كوشيار در بعضى تصانيف خود [3] اورده است كه معنى او ترازوي [4] آفتاب است [5] واز اينجاست كه [5] بعضى كمان برده‌اند كه اسطر ترازوست [6] ولاب آفتات بود [7] ودر بعضى [8] تصانيف ابي ريحان مذكور [9] است كه اصل او در لغت [10] يونان اسطرلابون [11] است ومعنى او آينه كواكب [12] ونزديكيست [12] باين آنجه بعضى آنرا [13] بستاره [14] ياب تفسير كرده‌اند وبعضى كفته‌اند كه اسطر تصنيف است ولاب نام پسر هرمس حكيم است [15] كه تسطيح [16] اسطرلاب اختراع اوست وشارح مقامات حريري از ابي نصر قمي نقل كرده [17] است كه جون لاب [18] ولد هرمس [18] دوائر فلكي را در سطح مستوي رسم ساخت هرمس ازو سؤال كرد كه من سطر هذا ودر جواب كفت سطره لاب وبدين سبب انرا [19] اسطرلاب كفتند ...

[1] في ج: وبعض . [2] في أ و ب: كنند . [3] في ج: خو . [4] في ب: ترازو . [5-5] في أ: و از ينحاست؛ في ج: و از پى است . [6] في ب: ترازو است . [7] ناقص في أ وج . [8] في ب: بعض؛ في ج: بعض نرر(؟) . [9] في أ وج: مسطور . [10] في أ و ب وج: لغة . [11] في ج: أسطرلابو . [12-12] في أ وج: نزديك است . [13] في ب: اورا . [14] في ج: ستاره . [15] ناقص في أ و ب . [16] ناقص في أ وج . [17] في أ وج: آورده . [18-18] ناقص في ب وج . [19] في ب: اورا .

(٢٥) فائدة في الأصطرلاب يقال إنها نقلت من النفحة المسكية

المصدر: مخطوطة لندن المكتبة البريطانية إضافية ٩٥٩٩، ق ٧ و

فائدة أما بطلميوس الفالوذي فإنه صنّف كتاب المجسطي [1] بكسر الميم والجيم وتخفيف الياء كلمة يونانية معناها ... [؟] [1] وهو أول من عمل الأصطرلاب وهو بفتح الهمزة وضمّ الطاء قال [2] كوشيار بن لبان بن باشهري الجيلي إن الأصطرلاب كلمة يونانية معناها ميزان الشمس وقال بعض الحكماء إن لاب اسم الشمس باليونانية [3] ا هـ من النفحة المسكية

[1-1] في الهامش . [2] في الأصل: هو (!) . [3] في الأصل: اليونان .

(٢٦) قطعة في الأصطرلاب من شفاء الغليل فيما في كلام من الدخيل لشهاب الدين الخفاجي

المصدر: مخطوطة دار الكتب المصرية مصطفى فاضل لغة ٢٠، ق ٧٥ ظ

... أصطرلاب والآلات التي يعرف بها الوقت أصطرلاب و الطرجهاره وهي آلة مائية وبنكام وهي رملية وكلها ألفاظ غير عربية ذكره في نهاية الأرب ...

(٢٧) قطعة من كشف الظنون لحاجّي خليفة

المصدر: النصّ المطبوع في استانبول عام ١٩٤١م، المجلد الأول، عمود ١٠٦–١٠٧

علم الأسطرلاب هو علم يبحث فيه عن كيفية استعمال آلة معهودة يتوصل بها إلى معرفة كثير من الأمور النجومية على أسهل طريق وأقرب مأخذ مبيّن في كتبها كارتفاع الشمس ومعرفة الطالع وسمت القبلة وعرض البلاد وغير ذلك أو عن كيفية وضع الآلة على ما بيّن في كتنه وهو من فروع علم الهيئة كما مرّ واصطرلاب كلمة يونانية أصلها بالسين وقد يستعمل على الأصل وقد تبدل صادا لأنها في جوار الطاء وهو الأكثر يقال معناها ميزان الشمس وقيل مرآة النجم ومقياسه ويقال له باليونانية أيضاً اصطرلافون واصطر هو النجم ولافون هو المرآة ومن ذلك سمي علم النجوم اصطرنوميا وقيل إن الأوائل كانوا يتخذون كرة على مثال الفلك ويرسمون عليها الدوائر ويقسمون بها النهار والليل فيصححون بها المطالع إلى زمن إدريس عليه السلام وكان لإدريس ابن يسمى لاب وله معرفة في الهيئة فبسط الكرة واتخذ هذه الآلة فوصلت إلى أبيه فتأمّل وقال من سطره فقيل سطرلاب فوقع عليه هذا الاسم وقيل أسطر جمع سطر ولاب اسم رجل وقيل فارسي معرّب من استاره ياب أي مدرك أحوال الكواكب قال بعضهم هذا أظهر وأقرب إلى الصواب لأنه ليس بينهما فرق إلا بتغيير الحروف وفي مفاتيح العلوم الوجه هو الأول وقيل أول من وضعه بطلميوس وأول من عمله في الإسلام إبراهيم بن حبيب االفزاري ومن الكتب المصنّفة فيه تحفة الناظر وبهجة الأفكار وضياء الأعين

(٢٨) قطعة من رسالة في الآلات الفلكية لمنجمك

المصادر: أ) مخطوطة دار الكتب المصرية ميقات ٧٣٥، ق ١ ظ
ب) مخطوطة دار الكتب المصرية ميقات ٧٠، ق ١ ظ

... المقالة الخامسة في رسم الآلات الحادثة عن تسطيح الكرة كالأسطرلاب الشمالي والجنوبي والزرقالة والشكازية والأرباع المستعملة بالخيط والمري مهدفة وهي مشتملة على عدة أبواب الباب الأول في رسم الأسطرلاب وهو آلة شريفة منسوبة إلى اليونانيين وأورد [1] كوشيار في بعض تصانيفه أن معناه ميزان الشمس ولهذا ظن أن اسطر ميزان ولاب شمس وفي بعض تصانيف أبي الريحان اسمها أسطرلافون [2] أي مرآة النجوم ولهذا خرج [له] [3] حمزة الإصفهاني من الفارسية ستاره ياب وزعم بعضهم أن اسطر تصنيف ولاب اسم حكيم اخترع الأسطرلاب وهو ابن هرمس الحكيم كما حكى [4] شارح المقامات الحريرية [4] عن أبي نصر القمي [5] أنه قال إن لاب لما رسم [6] الدوائر الفلكية في سطح مستو سئل هرمس بأن يقول من سطر هذا ويقول هو في جوابه [7] سطره لاب [7] ولهذا سموه بالأسطرلاب ...

[1] في ب: اورد . [2] في أ و ب: أسطرلاقون . [3] ناقص في أصل فانظر ملتقط رقم ٧ أعلاه . [4-4] في أ: شارح المقامات الحريري؛ وفي ب: صاحب المقامات الحريرية . [5] ناقص في أ . [6] في ب: رسم من . [7-7] في أ: سطرلاب .

(٢٩) حاشية لرسالة في العمل بالأسطرلاب لمؤلف مجهول علق عليها إسحاق الزكاني

المصادر: أ) مخطوطة دار الكتب المصرية طلعت ميقات ١،١٥٤، ق ١ ظ
ب) مخطوطة دار الكتب المصرية الزكية ٤،٧٨٢، ق ١٤ ظ
ج) مخطوطة دار الكتب المصرية ك ٢،٣٨٤٤، ق ١٥ ظ

الأسطرلاب بالسين وعند البعض بالصاد وقال كوشيار الحكيم في بعض تصانيفه معناه ميزان الشمس ومن ثمة ظن البعض تركيبه من لفظة اسطر ولاب الأول بمعنى الميزان والثاني بمعنى الشمس وفي بعض تصانيف أبي ريحان [1] هو في لغة يونان أسطرلافون [2] معناه مرآة الكواكب وبعضهم قال واحد الكواكب وقال بعضهم اسطر بمعنى التصنيف ولاب اسم ولد هرمس [3] الحكيم وهو أول من اخترع الأسطرلاب وقيل أول من اخترعه بطلميوس نقل شارح مقامات الحريري عن أبي النصر القمى [4] لما رسم لاب ولد هرمس [5] دوائر الفلك في سطح مستو قال هرمس [6] من سطر هذا قيل في جوابه لاب ومن ثمة قيل أسطرلاب هذا ما ذكر في شرح الفارسي [7] للرسالة الفارسية للنصير [8] الطوسي إسحق الزكاني [9]

[1] في ج: ركان . [2] في أ وب وج: أسطرلانون . [3] في أ وب وج: هرميس . [4] في أ وب وج: العمى . [5] في ج: هرميس . [6] في ج: هرميس . [7] في ج: الفازي . [8] في أ وب وج: للنصر . [9] في أ: الريحاني؛ وفي ب وج: الركالي .

حاشية أخرى للرسالة

المصدر: مخطوطة دار الكتب المصرية ميقات ٢١٣، ق ١ ظ

أسطرلاب معناه ميزان الشمس وقال كوشيار [1] يعني مرآة الشمس والأصحّ أسطر تصنيف ولاب ولد هرمس مصنفه يوناني

[1] في أصل: كشيار .

(٣٠) تعليق في هامش كتاب الأقنوم لعبد الرحمن الفاسي

المصدر: مخطوطة دار الكتب المصرية ٣٦٦٤ ج، ق ١٧٩ ظ

الأسطرلاب بفتح الهمزة وإسكان السين وضمّ الطاء ومعناه ميزان الشمس لأن اسطر اسم للميزان ولاب اسم للشمس بلغة اليونان وأول من وضعه بطلميوس بفتح الباء واللام وإسكان الياء والطاء وضمّ الميم (!!) وله في وضعه قصة عجيبة

(٣١) قطعة في الأسطرلاب من شرح منظومة عبد الرحمن الفاسي في الأسطرلاب لمحمد بنّاني بن عبد السلام بن حمدون

المصدر: مخطوطة دار الكتب المصرية تيمور رياضة ١١٣، ص ٩ – ١٠

قال ابن أبي الصلت هو آلة يتوصل بها إلى معرفة كثير من الأمور النجومية التعليمية على أسهل طريق وأقرب مأخذ فخرج بقوله على أسهل طريق إلى [1] آلات [2] الصفيحتين الزرقالية والشكازية [2] وربع دائرة ولفظه قيل كلمة أعجمية ومعناها عندهم قيل مقياس النجوم أو ميزانها وقيل لاب اسم للفلك باليونانية وقيل اسم لمخترع هاذه الآلة من متقدمي الحكماء وقيل أصله لاب بلام الجرّ ولفظته اب وهي عندهم اسم للمعلم والمراد به إدريس عليه السلام لأنه مستنبطه على ما قيل ثم فتحت لام الجرّ لمجاورة فتحة الهمزة بعدها وعلى [؟] كل فالأسطر جمع سطر اسم للرسوم التي فيه أي أسطر الفلك والحكيم فهو مركب إضافي نقل اسما للآلة وتعرف فيه بمقتضى لغة العجم في المنقول بالجمع بين ال (؟؟) والإضافة وتسكين آخر كل من الجزئين لاكنه يستدعي أن يكون همزة أسطر مفتوحة ولا تسمعها في الكلام إلا مضمومة منقولا ضمّها للام قبلها إلا أن يدعي التغيير المذكور فيه أيضاً على لغة من ذكر وحكى جماعة من المؤرّخين أن أول من وضعه بطلميوس صاحب المجسطي وأن سببه في وضعه أنه كانت معه [3] كرة فلكية وهو راكب فسقطت منه فداستها [4] دابتة فخسفتها فبقت عن هيئة الأسطرلاب وكانت أرباب الرياضة يعتقدون وإن هذه الصورة لا ترسم إلا في جسم كري على شكل الفلك فلما رءاه على تلك الصورة علم أنه ترسم في السطح وتحصل منه مقاصد الكرة فوضع وتقدم بوضعه على جميع الرياضيين ثم لم يهتد أحد منهم إلى أنه يتأتى المقصود من الأسطرلاب في الخط حتى ظهر الشيخ شرف الدين الطوسي شيخ كمال الدين ابن يونس فوضع المضموم من الأسطرلاب والكرة خط على عصى وكان قد سهى في بعض المواضع فأصلحها الشيخ كمال الدين ابن يونس وهذّبها لاكن الاستنباط للطوسي ...

[1] في الأصل: الخ . [2-2] في الأصل: الصيحتين الزرفانية السالشكازيح [هكذا] . [3] في الأصل: معود [!] . [4] في الأصل: فرامتها .

قطعة من الشرح المحتضر لمحمد بنّاني

المصدر: مخطوطة مكتبة محافظة الإسكندرية ٣٠٥٤ ج، ق ٤ ظ

... والأسطرلاب قال ابن أبي الصلت آلة يتوصل بها إلى معرفة كثير من الأمور النجومية التعليمية على أقرب طريق وأقرب مأخذ واسمه عجمي معناه عندهم مقياس النجوم وقيل لاب اسم الفلك باليونانية وقيل اسم لمستنيط هاذه الآلة وفي حياة الحيوان للعلامة الدميري أسطرلاب بفتح الهمزة وسكون السين وضمّ الطاء معناه ميزان الشمس لأن اسطر اسم الميزان ولاب اسم الشمس بلسان اليونان انتهى وأول من وضعه بطلميوس وله مع وضعه قصة غريبة حكيناها في الشرح ...

(٣٣) قطعة من كتاب رياض المختار لأحمد باشا مختار

المصدر: رياض مختار، ص ٢٣٨

نبذة تاريخية في الأسطرلاب وشرح لفظه الأسطرلاب لفظ مركب من كلمتين لاتينيتين اسطر بمعنى كوكب وعلى الأصحّ جرم سماوي ولابيوم بمعنى لوحة أو صفيحة وقد خفت الكلمة الثانية فصار الاسم أسطرلاب واستعملها بعضهم بدون تخفيف فقال أسطرلابيوم وهو كما لا يخفي عبارة عن تسطيح هيئة الكرة السماوية على ألواح صغيرة يمكن بواسطتها إجراء الحسابات المتعلقة بالأجرام السماوية وأول من ابتكر هذه الآلة واشتغل بها هو بطلميوس الذي عاش بالإسكندرية في القرن الثاني من الميلاد ...

Part XIVa-f

Selected late Islamic astrolabes

a) An astrolabe made by the Yemeni Sultan al-Ashraf
b) Some astronomical instruments from medieval Syria
c) A monumental astrolabe for the Ayyubid Sultan al-Muʿaẓẓam
d) An astrolabe for the Sultan Ulugh Beg
e) Two astrolabes for the Ottoman Sultan Bayezit II
f) Brief remarks on astronomical instruments from Muslim India
g) A universal astrolabe from 17th-century Lahore

Part XIVa

An astrolabe made by the Yemeni Sultan al-Ashraf

Dedicated to Owen Gingerich in 1985

DEDICATION, ACKNOWLEDGEMENTS AND NOTES TO THIS VERSION

This paper is dedicated to Professor Owen Gingerich of Harvard University and the Harvard-Smithsonian Center for Astrophysics as a small token of my appreciation. In 1971, when George Saliba and I were both studying with Professor E. S. Kennedy at the American University of Beirut, Owen Gingerich introduced these "terrible twins" to the delights of medieval astrolabes and modern computers. From our first encounter with some photos of various astrolabes attributed to ʿAbd al-Aʾimma that Owen had collected, we were able to distinguish between the real ones and the fake ones, and a joint paper ensued (listed under Gingerich & King & Saliba). After Owen had shown us the basics of Fortran, there was no looking back for either of us, and we were soon in the happy position of being able to generate tables of all sorts of functions tabulated by medieval astronomers. Thereafter, Owen played a major role in establishing, and obtaining continued support for, the Smithsonian Institution Project in Medieval Islamic Astronomy, based at the American Research Center in Egypt from 1972 to 1979. Had it not been for the privilege afforded me of using Cairo as a base during that period, the first volume of these studies of mine would never have been written.

It is a pleasure to thank the authorities of the Metropolitan Museum of Art in New York, the Institut du Monde Arabe in Paris, and the Egyptian National Library in Cairo for permission to publish photographs of instruments and manuscripts in their collections.

This study was first published as "The Medieval Yemeni Astrolabe in the Metropolitan Museum of Art in New York City", in *Zeitschrift für Geschichte der arabisch-islamischen Wissenschaften* (Frankfurt am Main) 2 (1985), pp. 99-122, with addenda and corrigenda *ibid*., 4 (1987/88), pp. 268-269, repr. in *Islamic Astronomical Instruments*, London: Variorum, 1987, repr. Aldershot: Variorum, 1995, II. In this version I have updated the references and provided numerous cross-references to other studies. An unauthorized Arabic translation of my text, with the *ijāza*s printed from my photos of the Cairo manuscript, but without any illustrations of the New York astrolabe (!), was published in *Dirāsāt fī taʾrīkh al-Yaman al-islāmī*, Sanaa: The American Institute for Yemeni Studies, 2002, pp. 164-189.

I have included as **Appendix A** descriptions of another medieval Yemeni astrolabe preserved in the Institut du Monde Arabe in Paris and of a Maghribi astrolabe made for use in the Yemen. I express my gratitude to Mme. Jeanne Mouliérac, formerly of the Institut du Monde Arabe for her collaboration over many years, and to Mr. Will Andrewes, formerly of the Collection of Historical Scientific Instruments at Harvard University, for his assistance during my visit in 1993.

Appendix B contains an overview of new information on the history of astronomy in the Yemen to supplement my *Mathematical Astronomy in Medieval Yemen* (1983). This overview

appeared in the form of an essay review entitled "Notes on Yemeni Astronomy in the Rasulid Period" of a facsimile edition of the *Anthology* of the Rasulid Sultan al-Afḍal (*The Manuscript of al-Malik al-Afḍal al-ʿAbbās b. ʿAlī b. Dāʾūd b. Yūsuf b. ʿUmar b. ʿAlī ibn Rasūl—A Medieval Anthology from the Yemen*, edited with an introduction by Daniel Martin Varisco and G. Rex Smith, Aris & Phillips Ltd, Warminster, Wiltshire, U.K., for the E. J. W. Gibb Memorial Trust, 1998), which was published in *Yemeni Update* 44 (2002), available on the Internet at www.aiys.org/webdate/afdking.html.

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1 Introductory remarks

In the Metropolitan Museum of Art in New York City there is preserved an astrolabe[1] made in the late 13th century by a prince of the Rasulid dynasty: see **Figs. 2.1-4**.[2] The maker was al-Ashraf ʿUmar, son of the Sultan al-Muẓaffar Yūsuf, and the instrument is dated 690 Hijra, that is, 1291, so that it was made shortly before al-Ashraf became Sultan of the Yemen for the brief period 1295-96.[3]

al-Ashraf's astrolabe did not fare too well in the hundred or so years after it was acquired by the Museum in 1891. Harrold E. Gillingham, who wrote on instruments in popular art journals, described it in 1924 as Persian.[4] It was described in four lines and the front was illustrated in Robert T. Gunther's *Astrolabes of the World* (1932), and Gunther, on the advice of Gillingham, who must have seen the light, wrote that:

> "Though the greater part of metal-work with silver inlaid decorations, bearing the names of the Rasulid Sultans, was probably made in Egypt, this astrolabe, with its simple decoration, is probably a local product of Yemen."[5]

In the 1960s, the distinguished historian of science, Derek J. de Solla Price, then involved in preparing a checklist of surviving astrolabes, communicated to the Metropolitan Museum his (unfortunate) opinion that this instrument was a 19th-century fake.[6] Perhaps it was such a consideration that led to the omission of this astrolabe from the 1972 publication *Islamic Art in the Metropolitan Museum of Art*.[7] Now once an artefact has been dubbed in any way suspicious, it never recovers. So in 1982, when the astrolabe was exhibited in Berlin along with other pieces from the Met, some very clever art-historian could not resist putting the word "probably" before the provenance "Yemen" at the head of a brief description by myself.[8] In

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[1] The instrument discussed in this study (#109 and #3549) is numbered 91.1.535 in the Museum's col1ection. It belonged to the bequest of Edward C. Moore, 1891, and its earlier provenance seems to be unknown. It is listed in Dimand, "Islamic Art at the Metropolitan Museum of Art" (1928), p. 107, no. 8, fig. 8, and in Mayer, *Islamic Astrolabists*, pp. 83-84. See also Price *et al*., *Astrolabe Checklist*, no. 3549; *Berlin MMA 1982 Exhibition Catalogue*, pp. 146-147 (no. 56), and Brieux & Maddison, *Répertoire* (forthcoming).

[2] On the Rasulid dynasty, see the article "Rasulids" in EI_2 by G. Rex Smith, and the basic details in Bosworth, *Islamic Dynasties*, 2nd edn., pp. 108-109. The vicissitudes of their reign are recorded by al-Khazrajī. On the city of Sanaa and its history, see Lewcock & Serjeant, eds., *Sana'a*.

[3] On al-Ashraf and his works, see al-Khazrajī, *The Pearl Strings*, text, I, pp. 284-298, and trans., I, pp. 236-246 (no scientific activities are mentioned!); Suter, *MAA*, no. 394; Brockelmann, *GAL*, I, p. 650, and SI, p. 901; Azzawi, *History of Astronomy in Iraq*, pp. 233-234; Sayyid, *Sources de l'histoire du Yemen*, pp. 131-132; al-Hibshi, *Maṣādir al-fikr al-ʿarabī al-Islāmī fi 'l-Yaman*, pp. 555-557; Ullmann, *Die Natur- und Geheimwissenschaften im Islam*, p. 342; and King, *Astronomy in Yemen*, pp. 27-29.

[4] Gillingham, "Pocket Sun-Dials", p. 3 (illustration of the front with the caption: "Persian Astrolabe, circa Thirteenth Century"). See also n. 6 below.

[5] Gunther, *Astrolabes*, I, p. 243 (no. 109), and plate LVI after p. 238.

[6] The maker's name is omitted from Price *et al*., *Astrolabe Checklist*, p. 12, under #109, where it is said to belong to the Collection of David Wheatland, Cambridge, Mass., but is given as "ʿUmar" under #3549 on p. 28, where it is listed under the holdings of the Met. In both entries the date is given as 695 H. Gillingham (see n. 4 above) had access to Wheatland's collection before the two men had a falling out.

[7] Listed under Ettinghausen *et al*.

[8] *Berlin MMA 1982 Exhibition Catalogue*, pp. 146-147 (no. 56). My description is not so brief that it was not clear that this very Yemeni astrolabe serving a series of latitudes in the Yemen was actually mentioned in a contemporaneous Yemeni manuscript penned by a Yemeni astronomer who was the teacher of the Yemeni sultan who made it in the Yemen.

any case, before 1985, when the first version of this study was published, the astrolabe had never been properly investigated, and alone a detailed description would have been of interest. However, there is a great deal more that can be said about this instrument than mere descriptive details.

There was considerable interest in mathematical astronomy in the Yemen from the 10th to the 19th century. This tradition is attested to in over 100 Yemeni astronomical manuscripts, preserved in various libraries around the world, which were first identified and surveyed about 20 years ago.[9] Amongst the various astronomers of the medieval Yemen were several sultans of the Rasulid dynasty. However, al-Ashraf was the only one of these who compiled extensive, substantial and original treatises on the subject, namely, one on instruments, and another on mathematical astrology.

al-Ashraf's treatise on instruments survives in a precious manuscript in Cairo, which is perhaps written in the hand of the Sultan himself. It deals mainly with the construction of the astrolabe and the horizontal sundial, and concludes with a section on the use of the magnetic compass that is of particular historical interest.

al-Ashraf's discussion of the astrolabe is unique of its genre, in that it contains tables for constructing astrolabe plates computed for specific latitudes in the Yemen and the Hejaz. Such tables were first compiled in the 9th century, and they were widely used at least in Egypt, Syria and the Yemen until the 19th century. The latitudes for which al-Ashraf presents tables for constructing astrolabe plates are precisely those for which his plates are constructed, which thus affords us a unique example of an astrolabe known to have been constructed using tables. Before this tradition of astrolabe tables was discovered, it was thought that Muslim astrolabists used only geometrical construction to draw the curves on astrolabe plates.[10]

Of still greater interest to our study are some notes appended to al-Ashraf's copy of his book on the astrolabe, written by two of his teachers. These describe, in the most laudatory terms, the various astrolabes made by the Sultan, one of which can be identified as the astrolabe now preserved in New York. None of the others is known to have survived. It is rare indeed that we find references in the medieval scientific literature to specific instruments, let alone to instruments that survive to this day. It is my hope that a detailed examination of the Sultan al-Ashraf's astrolabe, a preliminary investigation of his writings on the astrolabe, as well as an examination of the remarks of his teachers concerning the various astrolabes that he made, which is our present purpose, will serve:

(1) to give due prominence to a precious medieval artefact, hitherto thought to be of little consequence, and to illustrate the means by which it was constructed; and
(2) to revive the memory of a royal patron of astronomy from medieval Yemen, long forgotten as such even in his own land.[11]

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[9] See King, *Astronomy in Yemen*, for details of this tradition, and also **App. B** below.

[10] See Michel, "Construction des astrolabes persans", and *idem*, *Traité de l'astrolabe*, pp. 47-86, for details, and also **X-4.2**.

[11] A. Hibshi, a. modern Yemeni scholar, in his survey of medieval Yemeni writers and their works (see n. 3 above), mentions various scientific works by al-Ashraf, including his two treatises on astronomy, but refrains from further comment.

Fig. 2.1: The front of al-Ashraf's astrolabe (#109). [Figs. 2.1-4 courtesy of the Metropolitan Museum of Art, New York, bequest of Edward C. Moore, 1891.]

Fig. 2.2: The back of al-Ashraf's astrolabe.

2 The New York astrolabe of al-Ashraf

al-Ashraf's astrolabe—see **Figs. 2.1-4**—measures 15.5 cms in diameter, and the rete and four plates are 12.5 cms in diameter. The instrument is 0.5 cms thick. The maker's name and the date of construction are given on the rim of the lower left quadrant on the back of the instrument. The inscription reads:

هذا الأصطرلاب عمل عمر بن يوسف بن علي بن رسول المظفري مباشرةً وإملاءً سنة ٦٩٠

"This astrolabe is the work of ʿUmar ibn Yūsuf ibn ʿUmar ibn ʿAlī ibn Rasūl al-Muẓaffarī by his own hand and (also) under his supervision (*mubāshara*[tan] *wa-imlā*[ʿan]) in the year 690 (Hijra) [= 1291]."

Both N. Martinovitch (quoted by M. S. Dimand) and L. A. Mayer misread the date on the New York astrolabe as 695 H rather than 690. The "6" and the "9" in the inscription on the back of the instrument are written in standard Arabic numerical notation (derived from Indian numerals), but the zero is written with one of the symbols used in the standard Arabic alphanumerical (*abjad*) notation.[12]

The rim of the front of the astrolabe—see **Fig. 2.1**—bears a scale, the four quadrants of which are divided into 5° intervals subdivided for each one degree. The values of the arc measured on these four scales are given for each 5° in the *abjad* system, and values for each 10° are given in Indian numerals. This is most unusual.[13] There is a hole in the upper part of the mater, perhaps resulting from a flaw in the metal: compare the circular crack in the metal diametrically opposite.

The rete, which is basically in the simple ʿAbbāsid tradition (**XIIIc**), bears the standard representation of the ecliptic and positions of prominent stars. A small handle near the lower right edge can be used to rotate the rete and simulate the apparent diurnal motion of the heavens. Inside a scale bearing the names of the zodiacal signs on the circle of the ecliptic is a scale divided into 28 numbered subsections. These correspond to the 28 lunar mansions,[14] and the Arabic names for these are listed on the outer edge of the lower section of the rete. This is an unusual feature on any Islamic astrolabe, but in the Yemen, traditional folk astronomy, in which the lunar mansions were a prominent feature, flourished alongside the more sophisticated tradition of mathematical astronomy.[15]

All but four of the star pointers are for standard astrolabe stars. The Arabic names and the stars or groups of stars to which they refer, counted anticlockwise from the vernal equinox,

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12 See Irani, "Arabic Numeral Forms", and also Destombes, "Chiffres coufiques", on this convention.

13 Thus, when the same feature occurs on a modern fake astrolabe from India, one might well begin to suspect that the maker had access to a photo of this Yemeni astrolabe. See further *London Khalili Collection Catalogue*, I, pp. 237-238, and my "Review", col. 257.

14 On the lunar mansions, see the article "Manāzil" in EI_2 by Paul Kunitzsch.

15 On folk astronomy in the Yemen, see King, *Astronomy in Yemen*, pp. 3-4, 11-12, *etc*., and, more recently, Varisco, "Islamic Folk Astronomy", and *Yemeni Almanac*.

are presented in the following list. The numbers m/n identify the stars in the two main studies of Paul Kunitzsch dealing with astrolabe stars.[16]

1	*al-ghūl*	9/14	β Persei
2	*al-ḥādī*	24/18	α Tauri
3	*rijl al-jawzāʾ*	37/19	β Orionis
4	*yad al-jawzāʾ*	36/22	α Orionis
5	*al-shiʿrā*	39/23	α Canis Maioris
6	*al-shāmiya*	40/25	α Canis Minoris
7	*qalb al-asad*	26/30	α Leonis
8	*al-banāt**	Ø/40	α β γ δ Ursae Maioris
9	*al-aʿzal*	29/39	α Virginis
10	*al-rāmiḥ*	1/41	α Boötis
11	*al-fakka*	2/45	α Coronae Borealis
12	*al-ḥayya*	12/Ø	α ι κ λ Draconis
13	*qalb al-ʿaqrab*	30/48	α Scorpionis
14	*al-ḥawwāʾ*	11/51	α Ophiuchi
15	*al-wāqiʿ*	4/53	α Lyrae
16	*al-ṭāʾir*	13/54	α Aquilae
17	*ridf*	6/56	α Cygni
18	*al-faras*	19/58	ε Pegasi
19	*dhanab al-jady*	32/59	γ Capricorni
20	*al-muqaddam***	17+18/63+62	α β Pegasi
21	*muʾakhkhar***	15+16/1+3	α Andromedae, γ Pegasi
22	*khaḍīb*	7/2	β Cassiopeiae

* indicated by four dots just to the right of the centre of the horizontal diameter of the rete
** double pointers

The name *al-hādī* (2), meaning "(camel) driver", for *ḥādi ʿl-najm*, "the driver of the Pleiades, like a troop of camels", is unusual for *ʿayn al-thawr* or *al-dabarān* but is an old Arabic name.[16a] It is likewise unusual on Eastern Islamic astrolabes to find *al-banāt* or *banāt naʿsh* (8); however, it is common on Andalusī astrolabes from the 11th century. (These asterisms reappear on the astrolabes of Jean Fusoris and the Louvain school: see **Fig. XIIIa-10.7a-b**.) The double pointers marked

[16] Kunitzsch, "al-Ṣūfī and the Astrolabe Stars", pp. 158-161, and *idem*, *Arabische Sternnamen*, pp. 59-96.
[16a] *Idem*, *Sternnomenklatur bei den Arabern*, pp. 66-67 (nos. 119a-b).

al-muqaddim and *(al-)muʿakhkhir* (20-21) refer to the lunar mansions around Pegasus (*al-faras*),[16b] and I am not aware of having seen them on any other astrolabe. Burkhard Stautz has shown that the star-positions are very accurate for the date of construction.[16c]

Only three of the four plates are original. On the spurious plate, of earlier provenance and of considerable historical interest, see the end of this description. (On another plate attributable to al-Ashraf see **App. A2**.) Two of the six sides of the original plates are illustrated in **Fig. 2.3**. These are sextile or sexpartite (Arabic: *sudsī* or *qismat al-suds*), which means that they are marked with altitude circles for each 6° of argument. The altitude arguments 6, 12, ... , *etc*., are shown between the horizon (0°) and the 90° argument for the zenith.

The latitudes for which these plates were intended are inscribed just below the centre of each plate, together with the maximum number of hours of daylight for their latitude. No localities are associated with the latitudes, but these could easily be identified even if we did not have al-Ashraf's treatise. The latitudes and corresponding values of maximum daylight are:

13; 0°	12;46^h	[0]	[Aden]
13;37	12;48	[0]	[Taiz]
14;30	12; 5	[0]	[Sanaa]
15	12;54	[0]	[N. Yemen]
21	13;18	[0]	[Mecca]
24	13;31	[0]	[Medina]

The hours were accurately computed from the latitudes using 23;35° for the obliquity of the ecliptic, a standard medieval Islamic value,[17] which was popular amongst the Rasulid astronomers. The distinctive parameter 13;37° for the latitude of Taiz, which is accurate to the minute, seems to have been derived by the contemporaneous Yemeni astronomer Abu ʻl-ʿUqūl after he used 13;40° in his earliest tables (see **I-3.3.2** and **II-12.1**).

Each of al-Ashraf's plates bears markings for the afternoon prayer (*al-ʿaṣr*) in the upper right quadrant and for nightfall (*maghīb al-shafaq*) and daybreak (*al-fajr*) in the lower right and left quadrants, respectively.[18] These markings are curves (*khaṭṭ*, literally, "line") drawn between the circles representing the solstices.

Since the astrolabe can already be set up to display the configuration of the heavens relative to the local horizon at midday and at sunset, it suffices to mark the times of the (ʿ*aṣr*, nightfall and daybreak on the astrolabe, in order to use the instrument to measure time with respect to each of the five times of prayer. The curves for the afternoon prayer and for morning and evening twilight are *inlaid with si1ver*. al-Ashraf might also have inlaid the sections of the western horizon and the meridian between the solstitial circles to indicate the time of sunset and midday, and thus have drawn attention to each of the five times of daily prayer, but he chose to mark only three of them.

[16b] *Ibid*., p. 56.

[16c] Stautz, *Mathematisch-astronomische Darstellungen auf mittelalterlichen Instrumenten*, pp. 68 and 211. (The graphics shows the correspondence with Ptolemaic coordinates adjusted for the *Mumtaḥan* precession.)

[17] See the EI_2 articles "Mayl" (= declination) by D. A. King and "Minṭaḳa" (= ecliptic) by Paul Kunitzsch.

[18] On the prayer-times in Islam, see the articles "Mīḳāt" by C. E. Bosworth and D. A. King in EI_2, and on their origins and the way they were regulated over the centuries, see **IV** and **II**.
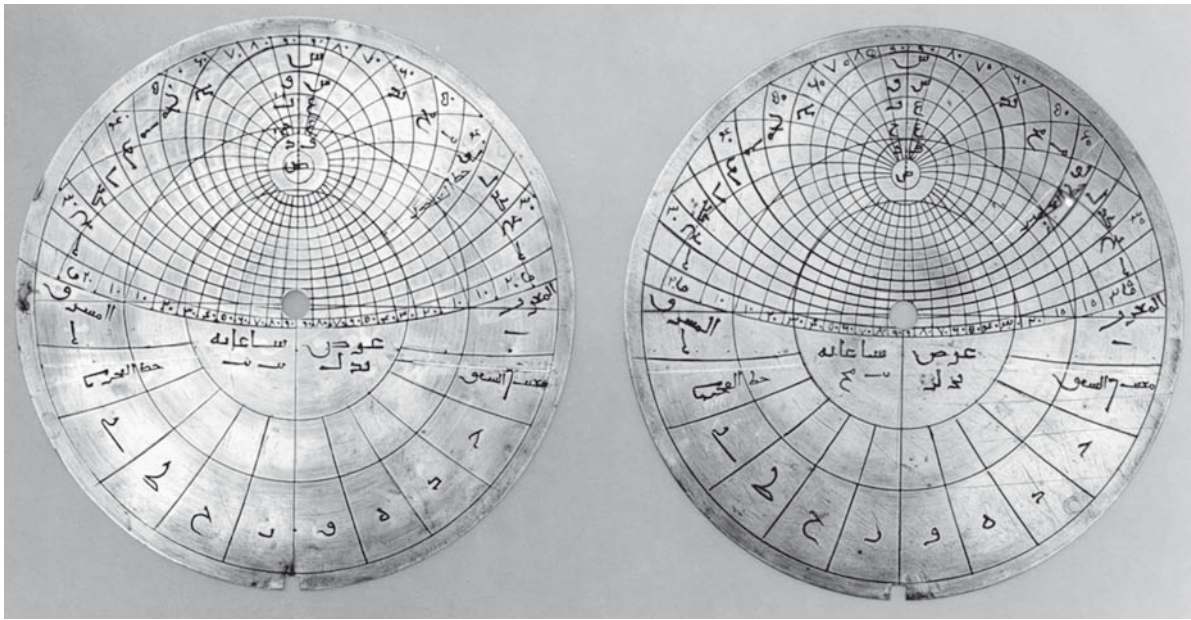
Fig. 2.3: The astrolabic markings for 13;37° (Taiz) and 14;30° (Sanaa) on two plates of al-Ashraf's astrolabe.

Each plate bears markings below the horizon for the twelve seasonal hours (*al-sāʿāt al-zamāniyya*), twelfth divisions of the length of day or night, which vary with terrestrial latitude and with the seasons.

On the back of al-Ashraf's astrolabe (see **Fig. 2.2**), there are two altitude scales for 0° to 90° marked in 5° intervals and 1° sub-intervals on the rim of the two upper quadrants. On the rim of the lower right quadrant is a scale of shadows marked *al-aqdām*, "feet". The scale displays the horizontal shadows that are cast by a vertical object seven "feet" long (that is, the height of a man) when the solar altitude is measured in the upper left quadrant.[19] The scale displays the arguments values 5, 10, 15, 20 and 25, each 5 units being subdivided into single units.

The other markings on the back are arranged according to the zodiacal signs starting with Aries, clockwise from the top. The names of the signs are written in Arabic (with the old form *al-samaka* for Pisces—see **XIIIa-2.4** and **3.16**, **XIIIc-1.1-3**, **2** and **3.1**), but the other information is written using planetary symbols that are identified by names at the centre of the instrument. See **Fig. 3.2** for the symbols in al-Ashraf's treatise. (These symbols were originally adopted by the Muslims from Hellenistic sources.[20])

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[19] For a more detailed discussion of such shadow scales, see Hartner, "Astrolabe", A, pp. 2545-2547, and now **XIIa-A**.

[20] See further al-Bīrūnī, *Tafhīm*, p. 199; Wiedemann, "Planetenzeichen auf Astrolabien"; and Ullmann, *Die Natur- und Geheimwissenschaften im Islam*, pp. 345-346 for tables of variants of such signs. More information on such symbols is contained in Gettings, *Dictionary of Occult Signs*.

Fig. 2.4: The alidade of al-Ashraf's astrolabe with its universal sundial and a remarkable conical sighting tube that fits in the holes of the vanes, and is clearly part of a Yemeni tradition (see **Fig. 2.5**).

There are three main scales of symbols. The outer one displays the "terms" (*ḥudūd*) of the zodiacal signs, five areas of unequal size for each sign, whose length in degrees is indicated by the number below the symbol of the planet associated with that term.[21] The middle scale displays the "lords of the faces" (*arbāb al-wujūh*), the faces being one-third divisions of each sign.[22] The inner scale displays the planets associated with the triangles or triplicities (*muthallathāt*).[23] Each of these comprises three signs each separated from the next by three others, and each is associated with one of the four elements: fire, earth, air and water. For each triplicity there is a "lord of the day", a "lord of the night" and a "companion". For each zodiacal sign these three planets are shown on the scale. All of these concepts were inherited by the Muslims from Hellenistic astrology.

The information on the back of al-Ashraf's astrolabe could have been considerably condensed in order to make room for more astronomically-significant markings such as a trigonometric quadrant.[24] Many Muslim instrument makers did not include astrological information of this kind on their astrolabes. Exceptions are, on the one side, al-Khujandī (**XIIIc-9**) and his followers, and the Iranian tradition right down to Safavid Iran, and, on the other, a Maghribi tradition exemplified by Abū Bakr ibn Yūsuf (Marrakesh *ca.* 1200).

The alidade—see **Fig. 2.4**—is most certainly original to the instrument. It bears a conical sighting tube that can be detached from the two rectangular vanes holding it in position. Alidades with sighting tubes are rare on Islamic astrolabes, but al-Ashraf does mention such tubes in his treatise—see **Fig. 3.2**. In addition to the two holes for this tube, the vanes each have an additional hole for sighting celestial bodies without the tube.

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[21] On the "terms", see further, for example, Hartner, "Astrolabe", A, p. 2548 (d/e); al-Bīrūnī, *Tafhīm*, p. 453; and Ptolemy, *Tetrabiblos*, I.20-21.

[22] On the "lords of the faces", see further Hartner, "Astrolabe", A, pp. 2548-2549 (f); and al-Bīrūnī, *Tafhīm*, pp. 262-263.

[23] On "triplicities", see further Hartner, "Astrolabe", A, p. 2549 (g); al-Bīrūnī, *Tafhīm*, pp. 230 and 259; and Ptolemy, *Tetrabiblos*, I.18.

[24] See, for example, Hartner, "Astrolabe", A, p. 2458, fig. 851, for the various markings on the back of a 13th-century astrolabe which bears, in addition to the astrological information recorded by al-Ashraf, two trigonometric grids and one horary quadrant, as well as scales for finding the solar longitude from the date in the Syrian calendar. These are illustrated in **Fig. X-4.6.1**.

The segment of the alidade between the bases of the two plates is divided into six unequal divisions and marked for each pair of zodiacal signs using *abjad* notation, thus:

1/12—2/1—3/10—4/9—5/8—6/7

This scale serves as a crude sundial when the alidade is held in the right way: see **XIIa-App. C**.[25] Whether this is original is unclear: certainly, the numbers are engraved in a hand different from that of al-Ashraf.

The decorated pin clearly belongs to the alidade, but the wedge (*faras*, literally "horse") for keeping the ensemble together is a crude replacement.

Replacement parts:

The fourth plate in the New York astrolabe is not original (see **Figs. XIIIc-12.2** and **XVI-3.2**), but, from the *kūfī* engraving, I would date it as early as the 10th century. Possibly it was made in the Yemen, for serious mathematical astronomy and *very* serious mathematical astrology were being practiced there already at this time, as witnessed by the surviving fragment of an astrological treatise by the celebrated scholar al-Hamdānī, who also authored an astronomical handbook with tables that has alas not survived.[26] This plate displays sextile markings for the altitude circles and also markings for the seasonal hours. The underlying latitudes are those of the 6th and 7th climates (Arabic: *iqlīm*), where the longest days are $15^1/_2$ and 16 hours, and where the latitudes are stated to be 41° and 48°. This plate comes from an astrolabe with markings for the climates: only one other such piece is known, namely, the earliest surviving Islamic astrolabe, from 8th-century Baghdad—see **XIIIb**. This particular plate clearly passed through the hands of a Byzantine craftsman, for the seasonal hours are crudely marked in capital Greek alphanumerical notation, in addition to the original markings in Arabic. See further **XIIIc-12.2**. As noted above, the wedge is a replacement.

3 al-Ashraf's treatise on the construction of the astrolabe

al-Ashraf wrote a treatise on astrolabe construction[27] that survives in two manuscripts, one copied in the Yemen in 692 H [= 1293] and now preserved in the Egyptian National Library in Cairo.[28] The other, now preserved in a library in Tehran, was copied in 888 H [= 1483/84] from the Cairo manuscript, but is in some disorder.[29] In the Cairo manuscript the title is given as *Muʿīn al-ṭālib ʿalā ʿamal al-asṭurlāb*, "The Student's Aid on the Use of the Astrolabe", and

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25 On p. 107 of the original publication I claimed that these markings served no sensible purpose.

26 King, *Astronomy in Yemen*, pp. 19-20 (no. 1).

27 On the treatise, see further King, *Astronomy in Yemen*, pp. 28-29.

28 This is MS Cairo TR (= Taymūr *riyāḍa*) 105, 149 fols., on which see *Cairo ENL Catalogue*, I, *sub* TR 105, and II, Section 4.1.2, and *Cairo ENL Survey*, no. E8.

29 The Tehran copy, MS MUI 150, was mentioned in Azzawi, *History of Astronomy in Iraq*, p. 234. A copy was kindly procured for me in the late 1980s by Professor Fuat Sezgin. In 1994 my doctoral student Petra Schmidl drew my attention to the fact that MS Berlin SB Ahlwardt 5811 (= Sprenger 1870) is an anonymous extract from al-Ashraf's treatise, copied in 1114 H [= 1702], to which is appended the section on the compass-bowl; this latter was translated by Eilhard Wiedemann in a short note "Die Geschichte des Kompasses bei den Arabern" (see also his article "Maghnāṭīs" in EI_2 and the addenda in my article "Ṭāsa").

in the Tehran manuscript it is given as *Manhaj al-ṭullāb fī 'l-ʿamal bi-'l-asṭurlāb*, "The Students' Course on the Use of the Astrolabe". Both of these titles may be spurious, not least because, as we shall see, the topic of the treatise is not restricted to the astrolabe alone. Also, most medieval texts on the astrolabe deal with the use of the astrolabe (*al-ʿamal bi-'l-asṭurlāb*); al-Ashraf's treatise belongs to a less common genre of scientific literature dealing with the construction of the astrolabe (*ʿamal al-asṭurlāb*). The following remarks are not intended as an overview of his treatise: I note only those aspects that relate to his astrolabe.

In the first part of his treatise, al-Ashraf refers to the extensive treatise on spherical astronomy and instruments by the late-13th-century Cairo astronomer Abū ʿAlī al-Marrākushī.[30] He also had access to some other astronomical works that are not named by him and that are no longer extant.

al-Ashraf's text is richly illustrated with diagrams. **Fig. 3.1** shows an astrolabe rete resembling that on al-Ashraf's surviving astrolabe (compare **Fig. 2.1**) and with a sub-group of its stars. **Fig. 3.2** displays precisely the information engraved on the back of the New York instrument (compare **Fig. 2.2**). Various kinds of alidades are displayed in **Fig. 3.3** including the type with a conical sighting tube. Some illustrations in the miscellany of the Yemeni sultan al-Afḍal (see **App. B**) display how the conical sighting tube is to be cut from a rectangular piece of metal, and what a real "horse" should look like, as well as a spring clip: see **Fig. 3.4**.

al-Ashraf also presents tables of coordinates—see **Figs. 3.5a-b**—are presented for marking the altitude and azimuth curves on astrolabe plates for each of the seven latitudes:

13°—13;37°—14°—14;30°—15°—21°—24°,

six of which are represented on his astrolabe. Note the distinctive value 13;37°, which is intended to be the latitude of Taiz.[31] These tables are similar in conception to those of the 9th-century Baghdad astronomer al-Farghānī, in turn inspired by a table of his early contemporary al-Khwārizmī.[32] The problem is, for a circle of altitude h on a plate for latitude ϕ, to generate values of its radius, r, and the distance of its centre from the centre from the centre of the plate, d: see **Fig. 3.6a**. al-Ashraf, like al-Marrākushī, reproduces al-Farghānī's table of an auxiliary function for generating such tables (fol. 84r). This function is essentially:

$$f(\theta) = R \tan (\theta / 2),$$

where R is the radius of the celestial equator on the astrolabe—see **Fig. 3.6b**. With this function, the radius r of the circle corresponding to celestial altitude h on a plate for latitude ϕ, and the distance d of the centre of the circle from the centre of the astrolabe—see **Fig. 3.6c**—are easily shown[33] to be given by the identities:

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[30] On al-Marrākushī and his work, see King, "Astronomy of the Mamluks", pp. 539-540, and the references to the publications of Sedillot *père et fils* there cited.

[31] See above and also **I-3.3.1**, *etc*., and **II-12.2**.

[32] On such tables see King & Samsó, "Islamic Astronomical Handbooks and Tables", pp. 91-92. On al-Farghānī see the article by A. I. Sabra in *DSB*. On al-Khwārizmī see the article by Gerald J. Toomer in *DSB*, and on his table for constructing astrolabe plates, see King, "al-Khwārizmī", pp. 23-27. On a 14th-century set of astrolabe tables compiled in the Yemen by the Egyptian astronomer al-Bakhāniqī (*Cairo ENL Survey*, no. C28), see King, *Astronomy in Yemen*, pp. 34-35. François Charette and I are currently preparing for publication a survey of Islamic astrolabe tables.

[33] See already Michel, *Traité de l'astrolabe*, pp. 62-63.

Fig. 3.1: The rete of an astrolabe featured in al-Ashraf's treatise. [From MS Cairo TR 105. Figs. 3.1-3.3, 3.5 and 3.7 are courtesy of the Egyptian National Library.]

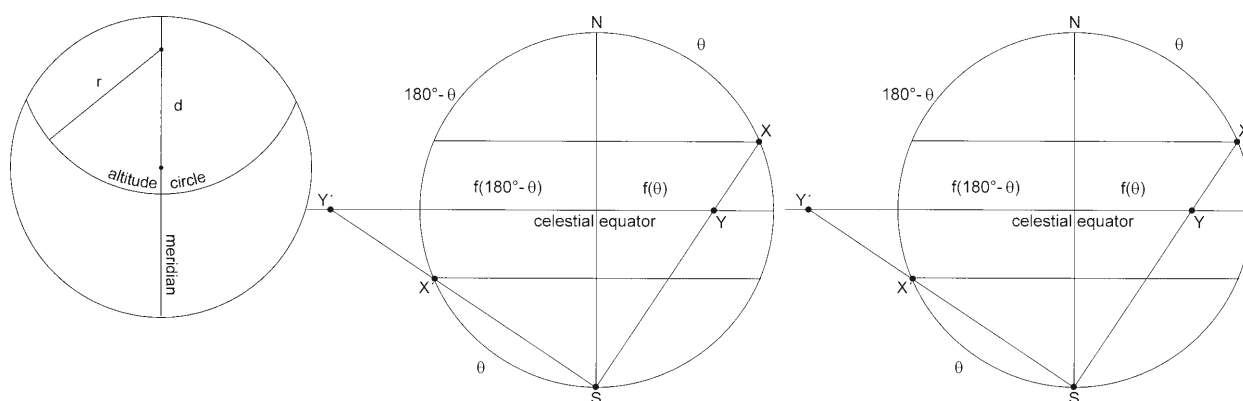
Fig. 3.2: The back of an astrolabe illustrated in al-Ashraf’s treatise, exhibiting the same kind of scales as found on his surviving astrolabe.

Fig. 3.3: Different varieties of alidades illustrated in al-Ashraf's treatise. [From MS Cairo TR 105, fol. 58v.]

Fig. 3.4: Illustrations of the paraphernalia necessary to keep an astrolabe together, as found in one of the treatises in al-Afḍal's miscellany (see **App. B**). Of particular interest is the construction of the conical sighting tube. [From Varisco & Smith, *al-Afḍal's Anthology*, p. 291, with kind permission of Professor Daniel M. Varisco.]

a

b

Figs. 3.5a-b: (a) Tables of d(h) and r(h) for each degree of argument h, for latitude 13;37°.
(b) al-Ashraf's tables of coordinates for marking the azimuth circles on astrolabe plates for latitudes 13;0° and 13;37°. [From MS Cairo TR 105.]

Figs. 3.6a-c: The principle underlying the tables of coordinates for marking the altitude circles on astrolabe plates.

$r(\phi,h) = R/2 \{ f(180° - \phi - h) + f(\phi - h) \}$ and $d(\phi,h) = R/2 \{ f(180° - \phi - h) - f(\phi - h) \}$. al-Ashraf's tables display both functions $r(\phi,h)$ and $d(\phi,h)$ for each of the values of ϕ stated above and each 1° of h. Similar tables are presented for marking the azimuth curves on the plates.

al-Ashraf presents two different star catalogues in his treatise (fols. 30r and 30v)—see **Figs. 3.7a-b**. In both, the information given for each star does not include the ecliptic or equatorial coordinates, as is usual in star catalogues. Rather, the degree of the ecliptic that culminates with the star (*al-daraja allatī tatawassaṭ al-samāʿ maʿ al-kawkab wa-hiya darajat al-mamarr*) and the radius of the day-circle of the star (*niṣf quṭr madār al-kawākib)* are presented. These are the radial coordinates for marking the stars on the rete of an astrolabe. (al-Farghānī's star catalogue in his treatise on the construction of the astrolabe is of the same kind.[34])

The first list is for 23 stars and is stated to be for epoch Dhu 'l-Qaʿda 685 [= December, 1286]. The second is for 17 stars and is stated to be according to the opinion of "Sharaf al-Dīn al-Ḥāsib", that is, the Cairo astronomer Abū ʿAlī al-Marrākushī, when he corrected the positions of "ʿAlam al-Dīn Taʿāsīf", that is, the mid-13th-century Egyptian scholar ʿAlam al-Dīn Qayṣar ibn Abi 'l-Qāsim, known as Taʿāsīf.[35] al-Ashraf adds some remarks about the position of the star α Scorpionis in 699 (?) H [= 1299/1300] according to al-Marrākushī (?) and Muʾayyad al-Dīn al-ʿUrḍī,[36] "student of Taʿāsīf". This information requires further investigation. Suffice it to remark for the present that neither list of stars in the manuscript corresponds to the stars featured on al-Ashraf's astrolabe.

Yet another list of 23 stars with their meridian altitudes for the different latitudes used by al-Ashraf appears on fols. 81v-82r. This can be used for checking positions of stars on the astrolabe rete. It is followed on fols. 82v-83r by a similar table for 24 stars based on the positions, *i.e.*, declinations, of al-Marrākushī for 680 H [= 1280].

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[34] See, for example, MS Berlin Ahlwardt 5792, fol. 3r.
[35] On this individual, see Suter, *MAA*, no. 358.
[36] On al-ʿUrḍī see Saliba, *The Astronomical Work of al-ʿUrḍī.*

Figs. 3.7a-b: al-Ashraf's table of coordinates for marking stars on astrolabe retes (left), and another table for the same purpose (right). Both are of considerable historical interest, and neither has been studied. [From MS Cairo TR 105, fols. 30r and 30v.]

In the second main part of his treatise, al-Ashraf deals with the construction of horizontal sundials, presenting tables of coordinates for marking the seasonal hours on the shadow traces of the zodiacal signs, computed for each of the latitudes mentioned above. These sundial tables are of the same kind as those of the 9th-century astronomer pseudo-al-Khwārizmī or Ḥabash, computed for a series of latitudes, and those of al-Marrākushī, computed for Cairo.[37] No medieval Yemeni sundials are known to have survived. al-Ashraf's work ends with a brief discussion of the use of the water-clock (*t/ṭarjahar*),[38] and on the use of the magnetic compass (*ṭāsa*) to find the qibla.[39] This latter text is of particular historical interest since it is the earliest attested reference to the compass in an Islamic astronomical source.[40]

Following the text of al-Ashraf's treatise in the Cairo manuscript are the two notes of approval or *ijāza*s by two of his teachers, which we consider in **4**.

al-Ashraf's treatise entitled *Kitāb al-Tabṣira fī ʿilm al-nujūm*, "The Book of Enlightenment in Astrology", extant in a unique manuscript preserved in Oxford,[41] deals not only with mathematical astrology, but also with timekeeping and folk astronomy—see **I-3.3.1** and **II-12.2**.

4 The comments of al-Ashraf's teachers on his astrolabes

The remarks of al-Ashraf's teachers appended to his treatise are of the genre called in medieval Arabic *ijāza*, "notice of approval", and were usually granted by teachers to students who had satisfactorily studied a particular written work.[42]

The text of these remarks, taken from fols. 147r-149v of the Cairo manuscript, was published in Damascus in 1952 in a little-known article by the Syrian scholar Ṭāhir al-Jazāʾirī.[43] The author was unaware of the existence of the New York astrolabe, and published the account because he had found it in the Cairo manuscript and considered it interesting. His rendition of the text contains over two dozen minor errors, and I have preferred to reproduce the original text, here illustrated as **Figs. 4.1a-f**. My translation may well need some revisions, because there are several passages that I do not fully understand.

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[37] On such tables see King & Samsó, "Islamic Astronomical Handbooks and Tables", pp. 92-94. On al-Khwārizmī see n. 32 above and on the sundial tables attributed to him, which may be by Ḥabash, see **I-4.1.1**, and the references there cited. On al-Marrākushī see n. 30 above, and on some of his sundial tables, see **I-4.1.3**.

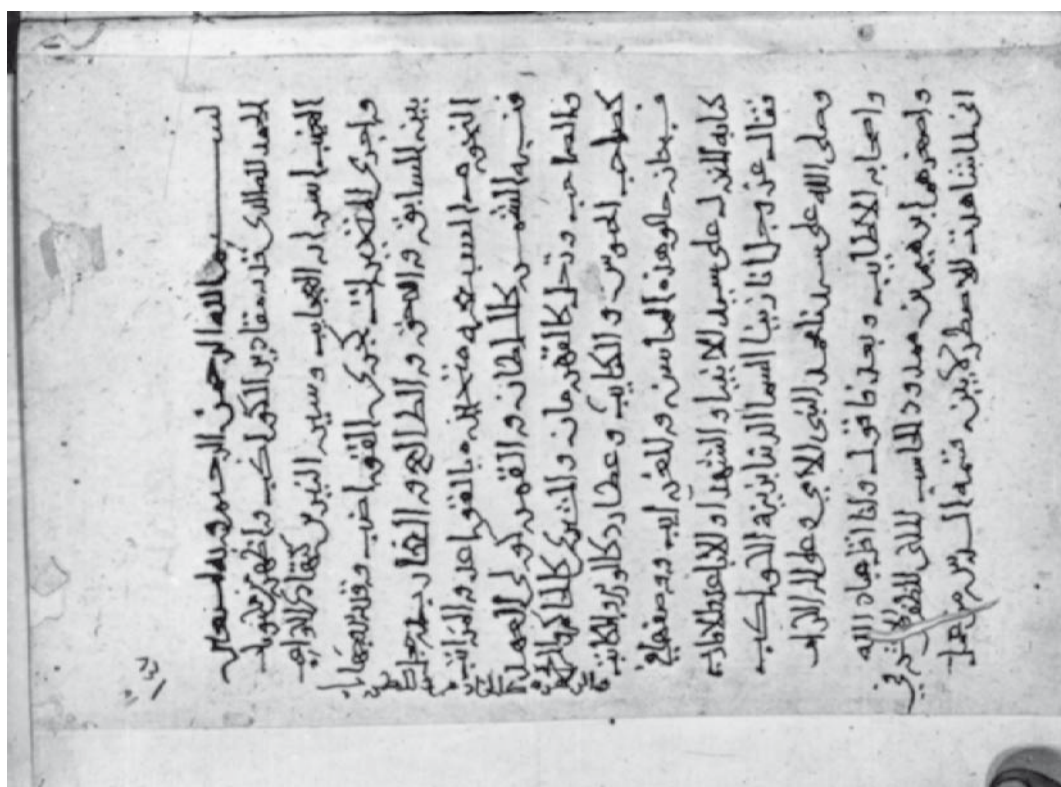
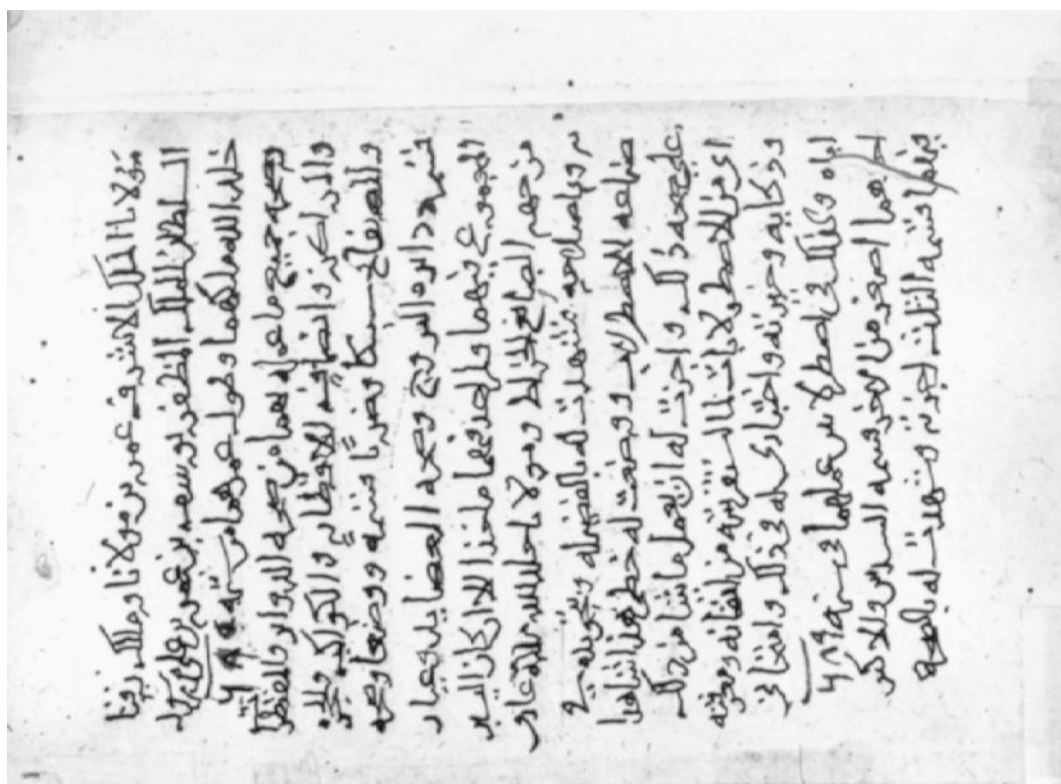
[38] This passage merits separate study. On Islamic water-clocks, see already Hill, *Pseudo-Archimedes on Water-Clocks*.

[39] On the qibla, see the EI_2 articles "Kibla" by A. J. Wensinck and D. A. King and "Makka (centre of the world)" by D. A. King, and now *idem*, *Mecca-Centred World-Maps*, pp. 47-127, and **VIIa-c**.

[40] The illustrations of the compass in the Cairo manuscript are reproduced in King, *Astronomy in Yemen*, pl. VII and *Cairo ENL Survey*, pl. LXIV. The text is published with translation and commentary in Schmidl, "Early Sources on the Compass".

[41] Extant in the unique copy MS Oxford Bodleian Huntington 233 (Uri 905), copied in the 14th century. See King, *Astronomy in Yemen*, p. 28 for further details, and **I-3.3.1** and **4.2.3** on various tables in this work.

[42] See, for example, the penetrating study of the *ijāza*s on a medieval Arabic literary manuscript in MacKay, "M*aqāmāt* Transmission Certificates", and also the EI_2 article "Idjāza" by Georges Vajda.

[43] See al-Jazāʾirī, "*al-Taʾlīf fī ʾl-mulūk*" (1952). The author is surely related to, if not identical with, the Damascene scholar of Algerian origin with the same name who was Director of the Ẓāhiriyya Library and who died in 1920: see Brockelmann, *GAL*, III, pp. 383-384, and İhsanoğlu *et al*., eds., *Ottoman Astronomical Literature*, II, pp. 706-707 (no. 545).

Figs. 4.1a-f: The text of some remarks by two of al-Ashraf's teachers on some astrolabes made by him: a unique document in the history of instrumentation and indeed in the history of Islamic science. [From MS Cairo TR 105, fols. 147r-149v, courtesy of the Egyptian National Library.]

c

d

The two sets of *ijāza*s between them do not give a clear idea of how many astrolabes are being described. It seems that al-Ashraf made two astrolabes in 690 H, one of which must be the New York instrument. Furthermore, it appears that he made two astrolabes in 689 H, one tertile or tripartite (with altitude markings for each 3° of argument) and the other sextile or sexpartite. However, the remarks in the first *ijāza* about his modifying a sextile astrolabe in 691 may refer to one of the instruments he made in 689 or 690. Also, the first teacher inspected in 692 some azimuth curves on a tertile astrolabe, which appears to be the instrument made in 689. Perhaps he added the azimuth curves at this later date. But in the second *ijāza*, it is stated that he actually made two sextile astrolabes in 691. Thus it seems that there are in all some six astrolabes under discussion.

The first *ijāza* is written in the hand of an ageing Ibrāhīm ibn Mamdūd al-Jallād al-Mawṣilī *al-ḥāsib al-maliki al-Muẓaffarī al-Ashrafī*, who is not known to me from any other source. The epithet al-Jallād indicates that he came from a family of leather merchants and al-Mawṣilī indicates that his family originated in Mosul in Iraq. The phrase *al-ḥāsib al-maliki al-Muẓaffarī al-Ashrafī* indicates that he was an astronomer (literally, calculator) in the service of the Sultans (literally, kings) al-Muẓaffar and his son al-Ashraf. The second *ijāza* is written in an elegant *naskhī* script by Ḥasan ibn ʿAlī al-Fihrī al-Muẓaffarī, whose name is also new to me. The epithet al-Fihrī indicates that his family was of Arabian origin, and *al-Muẓaffarī* indicates that he worked for the Sultan al-Muẓaffar.

A similar use of epithets is attested on a previously undocumented Andalusī astrolabe (#4299) that came to my attention in 2003.[44] It is signed by Muḥammad ibn ʿAbd al-ʿAzīz al-Khamāʾirī, whose name is new to the literature, and it is dated 624 H [= 1226/27]. He is clearly related to the prolific and well-known Muḥammad ibn Fattūḥ al-Khamāʾirī, who worked in Seville during the period 1210-40, and whose work is likewise spectacular.[45] This new piece bears a mark of ownership dated Cairo, 693 H [= 1293/94] by an Egyptian astronomer who signed himself Ibrāhīm *al-Ḥāsib al-Malikī al-Manṣūrī al-Ashrafī al-Nāṣirī*: see **Fig. 4.2**. al-Manṣūr became Sultan of Egypt in 678 H, and was succeeded by al-Ashraf in 689 H and by al-Nāṣir in 693 H. The signature on the London astrolabe of ʿAbd al-Karīm al-Miṣrī (#104), in which he is given similar attributes, has been faked, but is not without interest.[46]

In the translation of the *ijāza*s that follows I have to some extent suppressed the pious introductions of the two writers and the laudatory phrases which they apply to al-Ashraf.

The first set of ijāzas

"In the Name of God, the Merciful and Compassionate, ... I, the least and most insignificant servant of God, Ibrāhīm ibn Mamdūd *al-ḥāsib al-malikī al-Muẓaffarī al-Ashrafī*, say: I have seen two sextile astrolabes made by our Lord, the Sultan al-Ashraf ʿUmar, ..., in the year 690 [the date appears to have been altered from 68?], and (have inspected) the accuracy of all that he marked on them in the way of (concentric) circles, altitude circles (and their proper) centres and radii, the fixed stars and the mater and the plates, and also the way they were cast

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[44] I have no idea of the whereabouts of this piece, but have a set of photos of it from Sotheby's of London.
[45] Mayer, *Islamic Astrolabists*, pp. 64-66.
[46] *Ibid*., p. 30, and pl. XIIb.
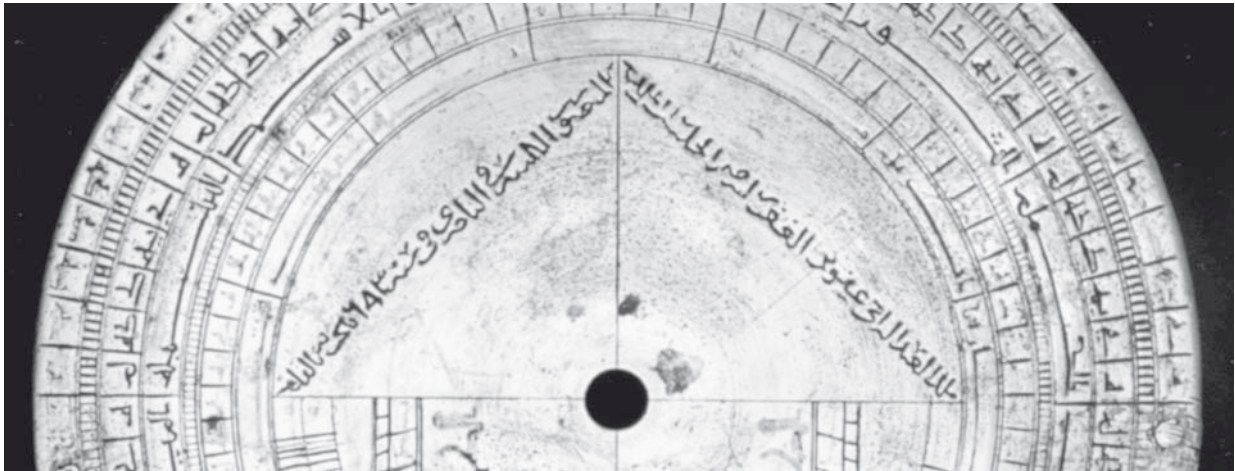
Fig. 4.2: The owner's signature on the back of an newly-rediscovered Andalusī astrolabe (#4299), which shows that it was in Egypt some 70 years after it was made, and that it was in the possession of a court astronomer-astrologer. [Courtesy of Sotheby's, London.]

and struck (*sabk*^{an} *wa-ḍarb*^{an}), and the way they are divided and constructed (*qisma*^{tan} *wa-waḍ*^{an}). (In addition, I have inspected) the accuracy of the divisions of the ecliptic and the alidades, and the quality of the metal used in both ensembles (*ʿiyār al-majmuʿ fīhimā*).

I found no fault in either of them except a little on the part of the craftsman turner, which our Lord ... knew about and could correct, so I make witness to him for his high degree of excellence in the construction of astrolabes, and I am writing for him in my own hand testifying to the accuracy of (all) this. I (also) give him permission to make whatever he likes in the way of astrolabes ... .

The same holds for the two astrolabes he made in the year 689, one of them smaller than the other, (the smaller) sextile and the larger of them tertile. So I give him approval and testify for him concerning the accuracy of the four above-mentioned astrolabes.

Likewise I grant him approval to mark the equatorial hours (on astrolabes ??) (*ajaztuhu fī ʿamalihi li-sāʿāt mustawiya*) which he would derive by means of a water-clock (*tarjahār*),[47] in whose theory and construction he excels [read *yuḥkimu* rather than y*aʿmalu*, as in the second set of *ijāza*s], and to make whatever he wishes in the way of (such clocks). Written by *al-Muẓaffarī al-Ashrafī* Ibrāhīm ibn Mamdūd al-Jallād al-Mawṣilī *al-ḥāsib* in the months of the year 690 Hijra ... .

Then I say ... ... that the Sultan al-Ashraf ... ... reworked a sextile astrolabe in the year 69l, with correct markings and full revision, more perfect than before, (a fact which) I took as evidence of the increase of his excellent skills ... ...

I also say that in the year 692 the Sultan ... ... drew my attention to the azimuth circles on

[47] On these, see n. 38 above. I am not sure how one would use a water-clock to mark the hour lines on an astrolabe plate.

a tertile astrolabe with azimuths for (each) ten (degrees of argument), so I investigated a lot about them, namely, the azimuth circles which he constructed by means of accurate instruments and by calculation. I found (the curves) to be extremely accurately drawn in their correct positions relative to each other, which I take as evidence of the accuracy of his hand, the excellence of his intellect, and his ability in constructing (instruments). So (for these reasons), I pronounce as accurate the azimuth circles he has drawn, and I approve his marking henceforth any astrolabes that he wishes with azimuth curves. Likewise, (I approve) his marking the seasonal and equinoctial hours, and the two curves for daybreak and nightfall, on any astrolabe he wishes. (I grant this approval) in Jumādā II of the year 692 ... ... Written by ... Ibrāhīm *al-ḥāsib* ... on the above-mentioned date."

The second set of ijāzas

"In the Name of God, the Merciful and Compassionate ... ... The servant (of God) who is most needy of Almighty God, Ḥasan ibn ʿAlī al-Fihrī *al-Muẓaffarī al-Ashrafī*, said: I have seen the astrolabes which our Lord ... ... al-Ashraf ... ... (so) skillfully and accurately constructed. Two of them are sextile and were made in the year 690. Two more, one sextile and the other larger than it and tertile, were made in the year 689. Two more, also sextile, were made in the year 691. I saw the accuracy of all the (base) circles and the altitude circles and the(ir) centres and radii, and the two intersecting diameters on the backs of (the astrolabes) that he had marked on them. I checked the edges [*ḥurūf* instead of *ḥiraf*] on the alidades that were used, the way the two sights stood on the alidades, and the way the holes on the sights lined up with each other, (ascertaining) that it was parallel to the edges of the alidades. I (also) checked each one of the pairs of altitude scales (lit., quadrants) on (these astrolabes), and their degree (markings) from 1 to 90, as well as the shadow squares and the twelve-digit and (seven-)feet shadow (markings). I (also) checked the quadrants of the mater on all of (the astrolabes), and their 360 degree (divisions), as well as the meridians with upper midheaven (?? *maʿa watad al-arḍ*) and the east-west lines, and also the way the ends of each of these diameters corresponded to the quadrants of the mater. (Furthermore I investigated) the altitude circles, the two solstitial circles and the equinoctial circle, the curves for the *ʿaṣr* prayer, daybreak and nightfall, as well as the seasonal hours. On the small sextile astrolabe made in the year 689, the curves for the equinoctial hours intersected with the curves for the seasonal hours [*i.e.*, both sets were drawn].

A few days later, I saw the tertile astrolabe made (by al-Ashraf) in the year 689. He had marked the azimuth curves (*sammata*) on its three plates for six latitudes, *viz*.:

13;0° [Aden] 13;37° [Taiz] 14;0° [?]
14;30° [Sanaa] 15;0° [?] 21;0° [Mecca]

I found the azimuth curves most precisely marked, their (main?) divisions (marked) for each set of ten azimuth curves (??). I found all of the astrolabes whose markings and dates I have mentioned, perfectly and accurately executed, and I approve his making and constructing astrolabes, including casting and striking them and drawing their markings (*ṣināʿat al-aṣṭurlābāt wa-waḍʿuhā sabk*[an] *wa-ḍarb*[an] *wa-rasm*[an]) because of what I have investigated of his precision, knowledge, intelligence, and perspicacity, and (also because) I tested and checked all of the instruments which he made so expertly.

Then I gave him my approval to construct whatever he wished in the way of equinoctial hours (??) (*sāʿāt mustawiya*) which he would derive by means of water-clocks (*ṭarjahār*), in whose theory and execution he excelled. I saw two water-clocks which he had constructed so excellently, one made of silver and the other of brass; I found both of them extremely well-made. So let him make (any such clocks) that he wishes.

I certify in this my own handwriting all that I have investigated concerning him and all that I have mentioned, and I certify to the acuteness of his knowledge and perspicacity, may God benefit him in his knowledge and labour, Amen. This (was done) on the second day of the month of Rajab, "the deaf one",[48] in the year 692, may God make (the year) have a happy conclusion, and may God bless our Lord Muḥammad and his family."[49]

5 Concluding remarks

A statement by al-Jallād that he did not find any fault with the two instruments made by al-Ashraf in 690 Hijra "except a little from the craftsman turner" which al-Ashraf "knew about and could correct" (*wa-lam ajid fīhimā maʾkhadh[an] illā in kān al-yasīr min jihat al-ṣāniʿ al-kharrāṭ wa-mawlānā ... ʿārif bihi wa-iṣlāḥihi*) seems to indicate that the Sultan did not make the component parts of the astrolabe himself. Yet the curious expression *mubāshara[tan] wa-imlāʾ[an]* in the inscription of the New York astrolabe seems to mean that the instrument was made "with his own hands and under his supervision". I surmise that al-Ashraf scratched the various markings on the plates according to his tables, and that an assistant did the engraving.

The workmanship on the New York astrolabe, as we can say without the inhibitions that must have restricted the Sultan's teachers, is not first-rate. Nevertheless, al-Ashraf's astrolabe is a fine example of an instrument made by a competent astronomer, and thus belongs to a rather small subgroup of surviving astrolabes. In addition, the fact that we have al-Ashraf's writings on astrolabe construction and the testimonies of his teachers about five similar astrolabes that he made, makes this a unique specimen in the history of Islamic astronomical instrumentation. Unique? Not quite! In September, 2004, I found another sextile plate attributable to al-Ashraf: see further **App. A2**.

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[48] The text has *al-aṣabb* for *al-aṣamm*, the epithet of the month of Rajab: a nice switch of labials already attested as a dialectal variant. See further Lane, *Lexicon*, II, p. 556c *sub Muḥarram*, IV, p. 1612a *sub shahr*, and IV, p. 1724b-c *sub aṣamm*. On the special epithets for the Islamic lunar months, see also Littmann, "Ehrennamen der islamischen Monaten".

[49] The mark of ownership beneath this text appears to read *bayt iftāʾ* (which could be Persianized Arabic for "the office of the *muftī*", although this seems unlikely) or *bayt afnād* (meaning?). Prof. Rudolf Sellheim of Frankfurt suggested the more reasonable reading *thal(ā)th amnān*, meaning "three *mann*s", where a *mann* was a unit of weight equivalent to *ca*. 800 grams. The notice would thus refer to the weight of this book—or a batch of books, for this particular book is not that heavy—in a sales transaction. The associated date is given as Ṣafar, 858 H [= February, 1454].

APPENDIX A: TWO OTHER YEMENI ASTROLABES

Both of the Yemeni astrolabes described below have a Maghribi connection. At least the first piece appears to have been made in the Yemen, and the latter probably also, although if this is the case, it is not clear why a plate for two latitudes in the Yemen was substituted for one of the original plates.

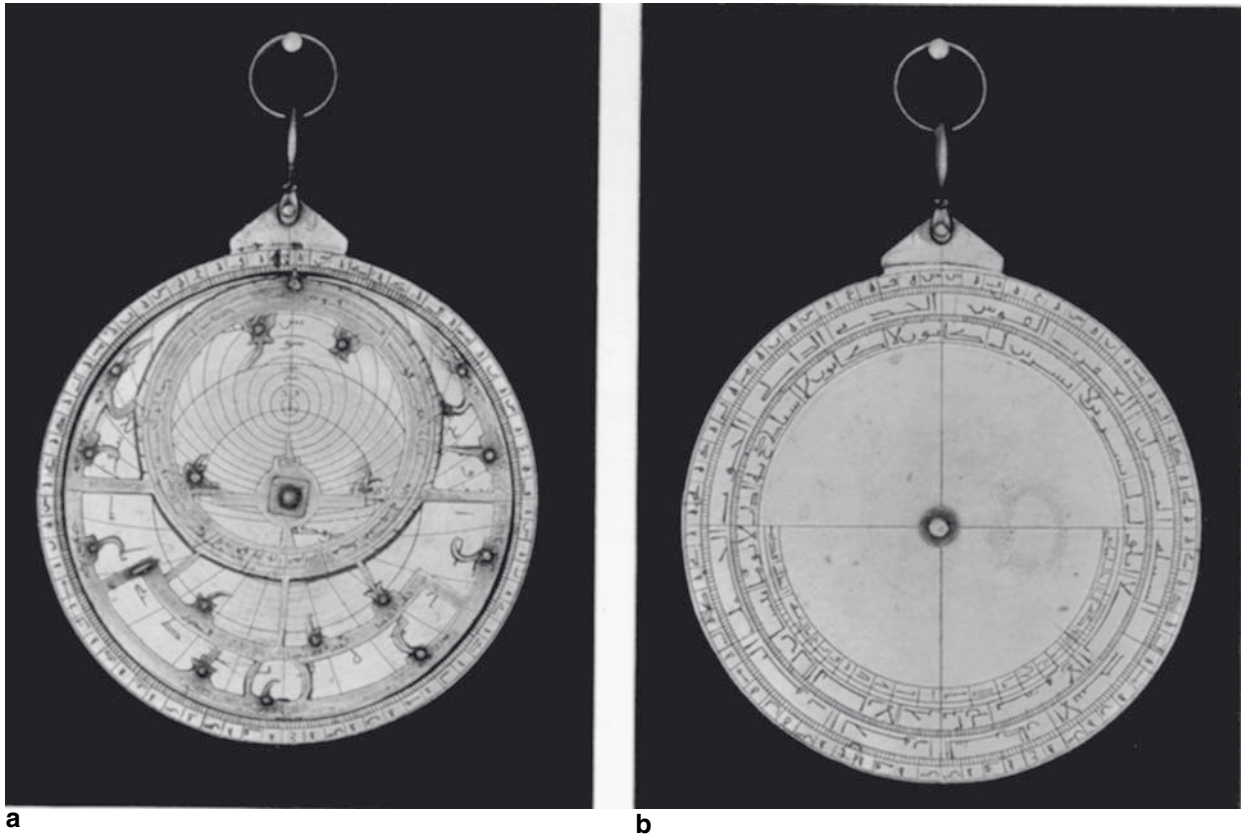
In my 1983 overview of the sources for the history of astronomy in the Yemen, I found, besides the obvious influence of the Cairo-based Abū ʿAlī al-Marrākushī, only a few fragments of the astronomical handbook of the early-13th-century Tunisian astronomer Ibn Isḥāq (now available in the Hyderabad copy of a Syrian recension). Clearly there were also Maghribi astrolabists working in the Yemen whose only concession to their Yemeni hosts was to use the Eastern Arabic *abjad* notation rather than the Maghribi one. However, they preferred not to abandon the Western Islamic traditions of astrolabe stars—the two different traditions are represented on the two pieces—and the distinctive Western Islamic star names (*al-ʿabūr* and *al-ghumayṣāʾ*)

1 An unsigned, undated Rasulid astrolabe in Maghribi style

An astrolabe preserved in the Institut du Monde Arabe (IMA) in Paris—see **Figs. A1-2**—is clearly a Rasulid Yemeni production, simpler (or less pretentious) than the surviving instrument of al-Ashraf.

International Instrument Checklist #4029.
Paris, Institut du monde Arabe, inv. no. AI.86.15; formerly in the collection of Marcel Destombes.
Brass, diameter 132 mm.
Bibliography: *Paris IMA Catalogue*, pp. pp. 89-90 (no. 5)—description by Jeanne Mouliérac.

The throne is simple, being raised and unabashedly triangular. The shackle and ring are original. The scale around the rim is divided for each 1° and labeled for each 5° in Eastern *abjad* notation for each 5° without hundreds or tens, and but for a peg at the bottom to hold the plates, the mater is empty.

The rete has the form of a Maghribi rete and the star names are in the Western Islamic tradition. Nevertheless, the inscriptions are in a lazy Eastern *kūfī*, in a different hand rather from the rest of the instrument. Nevertheless, there are certain peculiarities which suggest that it is original. The equinoctial bar is counter-changed once on each side within the equinoctial circle. The lower equatorial bar has two outer supports and a crude circular frame at the middle around the star Sirius. The ecliptic scale is divided for each 6° within each sign. There is a dummy pointer symmetrical to the one for Regulus. The right-hand support between the ecliptic and the circumferential frame is broken and the connection has been incompetently soldered. The star-pointers are in the *Western Islamic* tradition with silver studs at the base, and the following 17 stars are represented:

Figs. A1a-b: The front and back of the Paris astrolabe (#4029). [Courtesy of the Institut du Monde Arabe.]

baṭn qayṭūs
al-dabarān
rijl al-jawzāʿ

---

al-shiʿrā al-ʿabūr (barely legible)
al-shiʿrā al-ghumayṣāʾ
m-x-x-ʾ-ʿ [= *munīr min* ?] *al-shujāʿ* (position of star?)
qalb al-asad
janāḥ al-[ghurā]b (only partly visible)

---

al-simāk al-aʿzal
al-rāmiḥ
qalb al-ʿaqrab
al-ḥāwī (pointer broken)

---

al-[wā]qiʿ (stud missing)
al-nasr al-ṭāʿir
dhanab al-jady
mankib al-faras
dhanab qayṭūs

The three plates are marked with altitude circles for each 6° and no azimuth curves. The latitudes served by the plates are similar to, but not identical with, those on the contemporary instrument of the Sultan al-Ashraf, and for each a locality is specified:

13°	Aden
13;37	Taiz
14	Zabid
14;30	Sanaa
21	Mecca
24	Medina

The back bears four altitude scales, each measured from the horizontal axis, and *concentric* ecliptic and calendrical scales (Syrian calendar with the number of days in each month and with $28;15^{d}$ in Shubāṭ), running counter-clockwise from the left-hand extremity of this axis. There is no separate scale for the degrees of solar longitude (one has to use the altitude scales) and the days are not grouped as they usually are. The equinox is at Ādhār 12 full days, which corresponds to *ca.* 1400. Inside these, in the lower quadrants, are shadow-scales (bases 12 and 7). Otherwise, apart from the perpendicular diameters, the back is empty.

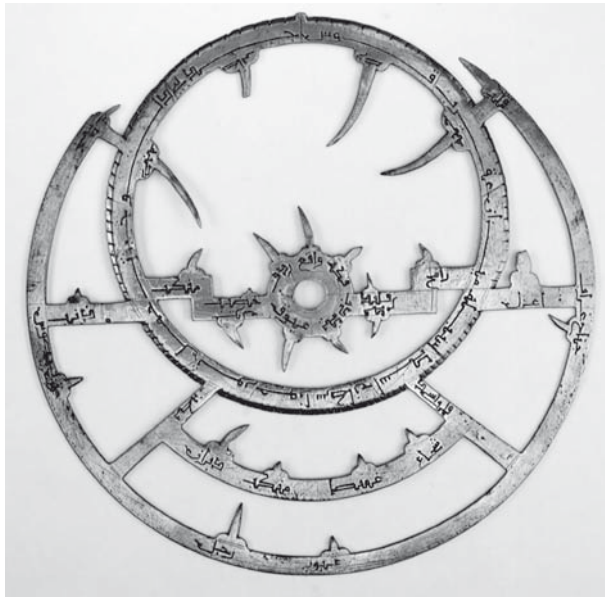
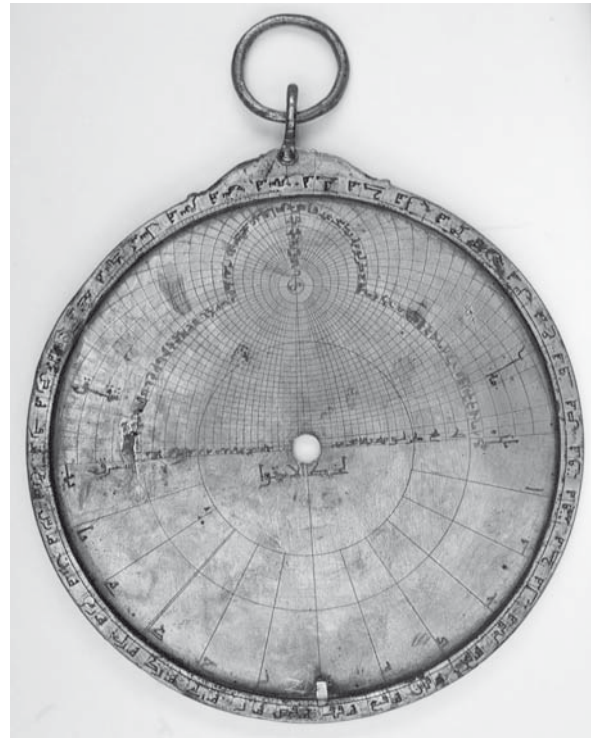
There is no alidade and the ensemble is held together by a modern nut and bolt.

2 A composite astrolabe made by a Maghribi craftsman in Syria or the Yemen (?) with a replacement plate by al-Ashraf

Another astrolabe of considerable historical interest is preserved in the Collection of Historical Scientific Instruments at Harvard University. I saw this piece in 1993, but could not examine it. Dr. Will Andrewes, then Curator of the Collection, kindly provided me with a full set of slides. The following description is based on an examination of the slides in September, 2004, whilst waiting for the proofs of this volume.

At first sight, we are dealing with a typical late Maghribi astrolabe, datable to the 15th century, with a rete and scales on the back that are definitely Maghribi in style. However, the solar / calendar scale on is for the months of the Syrian calendar, which means that the piece was made with Syria or the Yemen in mind. Alas, one of the plates is missing, so it is not possible to determine the provenance further. However, that plate has been replaced by one for two latitudes in the Yemen, which perhaps means that there was not such a plate originally. On the other hand, the latitudes served by the mater original plates are for the latitudes of Medina and Mecca and points south (0°, 12° and 15°).

International Instrument Checklist #4170.
Cambridge, Mass., Harvard University, Collection of Historical Scientific Instruments, inv. no. ?. Provenance ??
Brass. Diameter: ? cm.
Bibliography: None.

This astrolabe is at first sight typical of hundreds that were made in the Maghrib (mainly in Morocco) between 1200 and 1900. But the plates serve various localities in the Yemen and the Hejaz.

a

b

c

Figs. A2a-c: The rete, mater and back of the Harvard astrolabe (#4170). [Courtesy of Collection of Scientific Instruments, Harvard University.]

The throne is low and has a very small lobe on each side of the middle and a larger one at each extremity. The shackle and ring are relatively thin. The rim of the mater is divided for each 1° and labeled in Eastern Islamic *abjad* notation, that is, not in Maghribi *abjad*.

The rete is very simple, and its diametrical axis, counter-changed on each side of the celestial equator and again within, resembles those on 11th-century Andalusī retes (see **Fig. X-4.1.3**). The names of the signs are standard and the ecliptic scale is divided for each 3°. The following 27 standard *Western Islamic* astrolabe stars are represented:

matn qayṭūs	*ʿabūr*	*aʿzal* (broken)	*ṭāʾir* (broken)
ghūl	*ghumayṣā*	*qāʾid*	*ridf*
naẓīr (not a star)	*yad dubb*	*rāmiḥ*	*jady*
dabarān	*shujāʿ*	*qalb*	*rukba*
ʿayyūq	*qalb asad* (no pointer)	*ḥayya*	*mankib*
rijl	*qadam*	*[ḥā]wī*	*khaḍīb*
mankib	*janāḥ ghurāb*	————	*dhanab*
————	————	*wāqiʿ*	

There is no pointer for *qalb al-asad*, simply a strut. The symmetrical strut on the left is labelled *naẓīr*, "counter strut", a feature also found on Maghribi astrolabes. The back of the rete is devoid of markings.

The latitudes served by the markings on the mater and two original plates are:

0° (mater)	-	-
12°	-	$12;30^{h}$ [-13]
15°	-	12;48 [-8]
21°	[Mecca]	13;48 [0]
25° (25;30°)	[Medina]	13;35 [0]

The inscription on the mater reads *li-khaṭṭ al-istiwāʾ*, "for the equator". It bears altitude circles for each 3°. The azimuth curves are for each 4;30° and are labelled for each 9°. This latter arrangement is very unusual, but reminiscent of the 9° azimuth markings on two 11th-century Andalusī astrolabes, #118 and #1099.[1] On the fours sides of the two plates the altitudes are for each 3° and the azimuths for each 5°. On all five surfaces, the altitude and azimuth arguments are marked in a very elegant and ingenious way, reminiscent of some, but not all, of the astrolabes of Muḥammad ibn Fattūḥ al-Khamāʾirī (Seville, *ca*. 1200), for example, #4001.[2] The two sets of arguments on each side are combined along the horizon, up and around, and down the meridian. On all five surfaces there are special markings for twilight (*fajr* and *shafaq*) at 18° above the horizon. There is a peg at the bottom of the mater to hold the plates in position.

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[1] On the former see Gunther, *Astrolabes*, I, p. 253-256 (no. 118), especially pl. LX and fig. 121. Gunther overlooked these unusual markings.
On the latter see King, "Nuremberg Astrolabes", pp. 568-570 (no. 1.70), especially cols. 568c-569a.

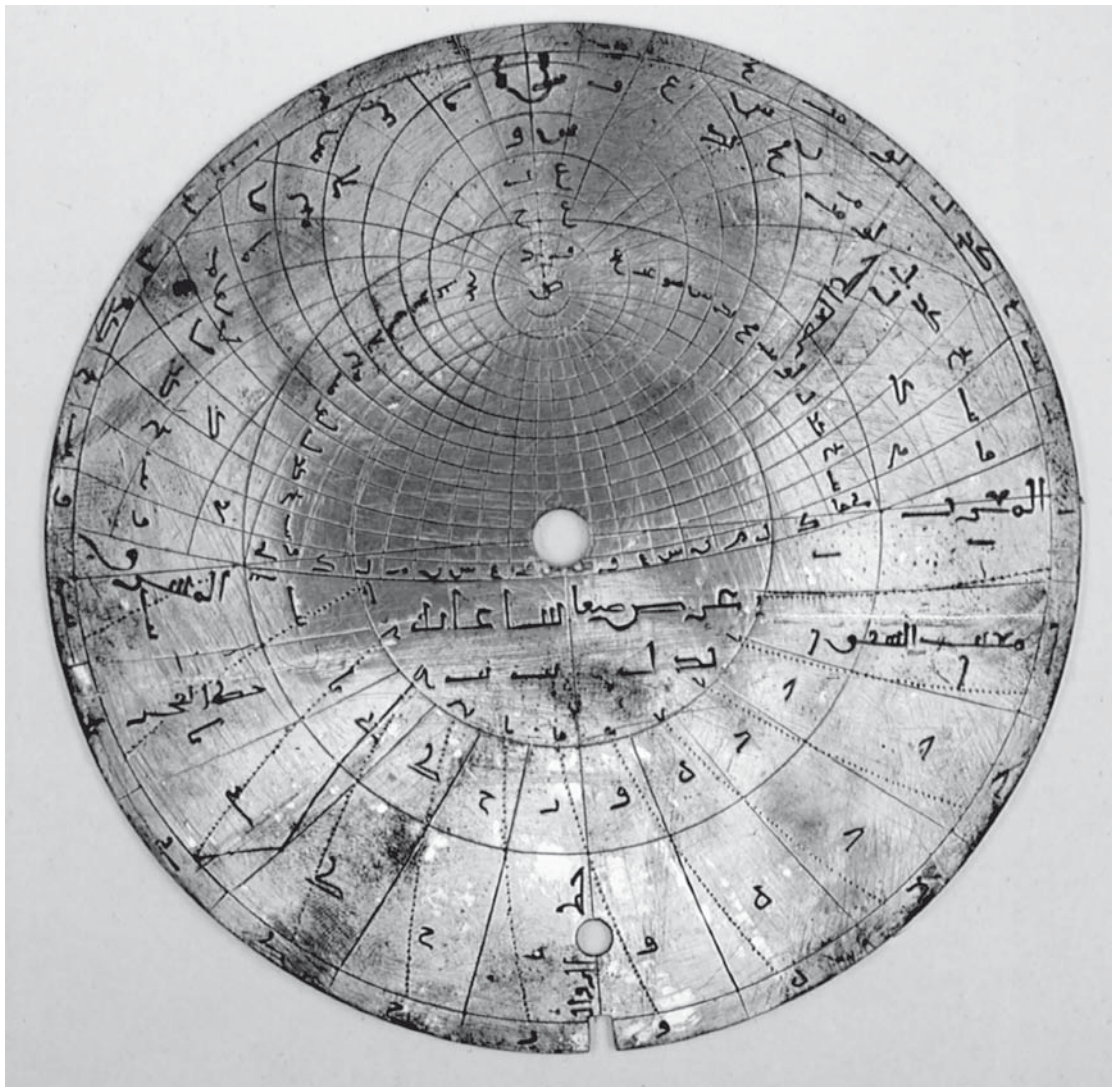
[2] On this see Sharon Gibbs and George Saliba in *Washington NMAH Catalogue*, pp. 184-187 (no. 4001), especially fig. 125.

d

Fig. A2d: One side of the plate for Yemeni latitudes, which should be compared with the plates of al-Ashraf's New York astrolabe in Fig. **2.3**. [Courtesy of the Collection of Scientific Instruments, Harvard University.]

The lengths of daylight are not without their problems. The values for latitudes 21° and 25° confirm that they are based on (and accurately computed for) the Ptolemaic obliquity, 23;51°. However, the latitude corresponding to 12;30^h should be slightly more than 12°. Actually, 12;30° is the latitude of the beginning of the first climate for obliquity 23;51°. Then the 48 minutes of the 12;48^h for latitude 15° could be read 12;58, which would be more accurate, and it should be noted that 12;58° is accurate for latitude 16° anyway. Why should the maker have made plates for these latitudes anyway, unless he was thinking of the beginning (12;30°) and middle of the first climate (16;27°)? The only other surviving plate, for Mecca and Medina, is less problematic. Daylight is accurate for latitudes 21° and 25°, but the maker has added a distinctive Maghribi hooked *lām* above the 25 to change it to 25;30° (for which daylight would be 13;37^h).

The back has four altitude scales around the rim, divided for each 1° and labelled for each 5°. Inside these are solar and calendrical scales for finding the solar longitude for a given day of the Syrian or Coptic year. Such scales, albeit for the Western calendar, are standard on Maghribi astrolabes (but not on astrolabes from the central regions of the Muslim world). The solar and calendrical scales are divided for each 1° and each 1^d, and labelled for each 5° and 5^d, respectively. The names of the zodiacal signs and the Syrian and Coptic months are standard, and the equinox is at *ca*. Ādhār $11^1/_3$, which corresponds to *ca.* 1450. The shadow square, marked for each 3 units up to 12 and labeled *mabsūṭ* and *mankūs*, is abnormally (and absurdly) small, each scale being about one quarter of the radius. There is an unusual design on the back formed by two contiguous circles.

The alidade and radial rule bear no markings, and the horse has a rectangular hole along its length.

Replacement parts: One plate quite different from the other two bears strong resemblance, not only in the engraving but also in the style, to the plates in the New York astrolabe of al-Ashraf. It bears altitude circles for each 6° and azimuth circles for each 10°. The locations served are:

14;0°	Zabid	$12;50^h$ [0]
14;30°	Sanaa	12;52 [0]

The lengths of daylight are accurately computed for obliquity 23;35°, as on al-Ashraf's plates. The altitude arguments are engraved three times for lower altitudes, one set being outside the circle of Capricorn. There are curves for twilight below the horizon, with the distinctive pair of labels *maghīb al-shafaq* and *khaṭṭ al-fajr*, and a curve in the upper right labeled *khaṭṭ al-ʿaṣr*, originally if not still inlaid in silver, as on al-Ashraf's plates. Similarly the meridian is labeled *khaṭṭ al-zawāl*. There is a hole at 0.8 of the outer radius below the centre, which indicates that this plate was originally prepared for another astrolabe.

* * * * * * * * * *

Here then are two more testimonials to the active interest in mathematical astronomy in the Yemen that lasted for many centuries. No doubt there are more such Yemeni instruments, and if this study leads to the identification of others in private collections in the Yemen, then nobody will be more gratified than the author.

APPENDIX B: NOTES ON YEMENI ASTRONOMY IN THE RASULID PERIOD

The following is intended to supplement my *Mathematical Astronomy in Medieval Yemen* (1983). It is essentially the text of an essay review of a recent publication *The Manuscript of al-Malik al-Afḍal al-ʿAbbās b. ʿAlī b. Dāʾūd b. Yūsuf b. ʿUmar b. ʿAlī ibn Rasūl—A Medieval Anthology from the Yemen*, edited with an introduction by Daniel Martin Varisco and G. Rex Smith, Aris & Phillips Ltd, Warminster, Wiltshire, U.K., for the E. J. W. Gibb Memorial Trust, 1998. It appeared in *Yemeni Update* 44 (2002), available at www.aiys.org/webdate/afdking.html.

The Rasulid Sultan al-Afḍal (d. 1377) was a cultured man, interested in many aspects of the world around him and its history. He is known to have compiled a dozen or so works, mainly on history but also on agriculture, medicine, astronomy and magic, only half of which are known to have survived. As if by way of compensation for us historians of the Yemen, there has been preserved for us an anthology by an unidentified copyist (possibly one of his recent ancestors?) dealing with all manner of subjects, which was once in his possession, for it includes notes in his own hand written the year before he died. No amount of praise is adequate for the copyist and for al-Afḍal; for its present owner, who had the foresight to make it available for a facsimile edition; and the two editors, who recognized its potential value for future research. Inspired and encouraged by the late Professor Robert Bertram Serjeant, to whose memory the volume is dedicated, the last two mentioned valiantly acquired photographs of the whole manuscript with over 540 pages, and ordered them in an entirely sensible fashion, now paginated. They also included a brief introduction to the Rasulids, on whom Rex Smith is the expert outside the Yemeni world, and to al-Afḍal, as well as providing a most useful table of contents for the manuscript in 15 pages. Their goal was achieved in making this remarkable historical document available to a wider public.

It is almost five years since that facsimile of al-Afḍal's *Anthology* was published. How dare a reviewer delay so long to write a review of a book edited by a pair of colleagues and friends? The reason is simple: what Dan Varisco hoped I would produce was a detailed overview of the extensive sections of the anthology dealing with astronomy, astronomical instruments and astrology. This, alas, is still not forthcoming. Rather, what I shall do is simply to repeat the gist of what I wrote some 20 years ago on the astronomical content of this manuscript, adding a few bibliographical references to point to some more recent research on Yemeni astronomy in general, that is, not just on this manuscript. It would be inappropriate not to mention various studies of other parts of al-Afḍal's *Anthology* that have appeared since the publication of the facsimile. These include Golden, ed., *Rasulid Hexaglot* (2000), and Varisco, "Agriculture in Rasulid Zabid" (2002).

My first encounter with al-Afḍal's manuscript was in 1970-71 at the American University of Beirut, where I had the pleasure of studying Ancient South Arabian with Professor Mahmoud Ghul. I was conducting research for my doctoral dissertation on the works of the Fatimid astronomer Ibn Yūnus and happened to mention to Professor Mahmoud Ghul that some of the Egyptian scholar's works had been known in the Yemen, whereupon he allowed me to make a copy of his microfilm of al-Afḍal's *Anthology*. It was thus as a result of his kindness that I was able to include an overview of the astronomical contents in my book on Yemeni astronomy that was published some 10 years later (*Mathematical Astronomy in the Medieval Yemen*, 1983, hereafter abbreviated *MAY*). I also analysed some of the tables in that manuscript that related to timekeeping, but only now, 30 years later, are those descriptions finally published (in **I-II** of the present work).

Overviews of the two traditions of Islamic astronomy, the first as practiced by the astronomers of medieval Islam and the second, non-mathematical folk astronomy, as practiced by the legal scholars, are to be found in King, "Islamic Astronomy", and Varisco, "Islamic Folk Astronomy", both in Selin, ed., *Astronomy across Cultures*. The recent overview King & Samsó, "Islamic Astronomical Handbooks and Tables", includes the most important Yemeni examples. Research on these Yemeni *zīj*es is being continued by Benno van Dalen; for further information see his website.

The following is a brief account of the astronomical contents of the *Anthology* (expanded from *MAY*, p. 37, *ad* al-Afḍal (no. 18)):

❖ There are numerous passages and tables taken from the *Kitāb al-Mabādiʾ wa-'l-ghāyāt fī ʿilm al-mīqāt*, "An A to Z of Astronomical Timekeeping", by the late-13th-century Cairo astronomer Abū ʿAlī al-Marrākushī (see now my article "al-Marrākushī" in EI_2). This important work is now available in facsimile edition (Frankfurt, 1984), in addition to the well-known studies of the Sédillots *père et fils* from the 19th century (repr. Frankfurt, 1985 and 1989). It still awaits detailed study, but it has been exploited in the study of a later Egyptian work by Najm al-Dīn al-Miṣrī in Charette, *Mamluk Instrumentation*.

❖ There are various tables taken from the *Muṣṭalaḥ Zīj*, which was the most-widely used *zīj* in Mamluk Cairo, but which alas does not survive in its original form (King & Samsó, "Islamic Astronomical Handbooks and Tables", p. 50). On one of these see further below.

❖ There are some tables taken from the extensive corpus of tables for timekeeping by the sun and the stars entitled *Mirʾāt al-zamān* and compiled *ca*. 1300 for the latitude of Taiz by Abu 'l-ʿUqūl (*MAY*, no. 9). The tables in this corpus are now analysed in **I-2.1.2**, *etc*., and **II-12.1**. Furthermore, more information on the elusive author has been discovered (see Varisco, *Yemeni Almanac*, p. 13): he is Muḥammad ibn Aḥmad al-Ṭabarī, the first teacher appointed by the Sultan al-Muʾayyad to his new madrasa in Taiz.

❖ Some geographical tables attributed to the late-12th-century Syrian astronomer Ibn al-Dahhān are all that survives from that author. See now **II-9.1**.

❖ Some tables are attributed to Ibn al-Mushrif (*MAY*, no. 12), who is not identical with

a 14th-century Egyptian astronomer with that name. See further **I-9.8**, *etc*., and **II-6.15**.

- Some planetary tables are stated to be from the *Kitāb al-Shams al-Ḥarīrī*, presumably a *zīj* by one Shams al-Dīn al-Ḥarīrī, otherwise unknown and not yet identified.
- Other tables are taken from the Yemeni *Muẓaffarī Zīj* of al-Fārisī (see King, *MAY*, no. 6.3, and King & Samsó, "Islamic Astronomical Handbooks and Tables", p. 52).
- Other tables are taken from the Iranian *Īlkhānī Zīj* of Naṣir al-Dīn al-Ṭūsī (see King & Samsó, "Islamic Astronomical Handbooks and Tables", p. 46).
- An almanac displaying various spherical astronomical functions for each day of the solar year is introduced in the name of al-Afḍal himself but the same almanac occurs in the Berlin manuscript of the *Mirʾāt al-zamān* of Abu 'l-ʿUqūl (see above). This is mentioned in Varisco, *Yemeni Almanac*.
- A short treatise of one page attributed to al-Afḍal deals with a celestial sphere that he made in 776 H [= 1374]. Alas, all other traces of this instrument have disappeared and it is not mentioned in Savage-Smith, *Islamicate Celestial Globes*.
- A table displaying the solar longitude for each day of the year is stated to have been compiled by al-Afḍal in 777 H [= 1375/76].
- A short treatise on the astrolabe is attributed to the Rasulid Sultan al-Mu'ayyad (*MAY*, no. 10); this is not known from other sources.

I concluded my first description 20 years ago with words that are still valid:

> "A more detailed description of the contents of this manuscript would obviously be worthwhile, but the need for investigations of the works of al-Marrākushī, the Egyptian *Muṣṭalaḥ Zīj*, and the Yemeni *Muẓaffarī* and *Mukhtār Zīj*es, is more urgent."

In my 1983 book, I identified two Yemeni ephemerides (*taqwīm*, pl. *taqāwīm*) for the years 727 H [= 1326/27] and 808 H [= 1405/06], unique of their genre (*MAY*, nos. 11 and 22). We have only fragments of similar works preserved in a citation by al-Bīrūnī and leaves from the Cairo Geniza. A detailed investigation of these ephemerides is in preparation as a doctoral thesis by Michael Hofelich of Frankfurt: see already his article "Taḳwīm" in EI_2.

I also pointed to the importance of certain early Yemeni works on folk astronomy for our understanding of aspects of Islamic ritual. We note the following more recent and other imminent publications:

- An analysis of the Yemeni materials on timekeeping by arithmetical and other simple shadow-schemes: see **III-4**.
- The agricultural almanac of al-Afḍal has been published with a detailed commentary: see Varisco, *Yemeni Almanac*.
- A study of a text by the mid-13th-century scholar Muḥammad ibn Abī Bakr al-Fārisī of Aden (*MAY*, no. 6.1) on the astronomical orientation of the Kaʿba: see now Hawkins & King, "Orientation of the Kaʿba".
- The materials on sacred geography—the notion of the world divided into sectors about the Kaʿba at the centre—in Yemeni sources, in particular a reconstruction of three schemes proposed by the Yemeni *faqīh*, Muḥammad ibn Surāqa, *ca*. 1000 (see *MAY*, p. 21)—have been analysed together with similar materials from other regions. See

King, *The Sacred Geography of Islam*, as yet unpublished, with a summary in the article "Makka. iv. As centre of the world" in EI_2, repr. in King, *Studies*, C-X.

- A detailed study by Petra Schmidl of the materials relating to the prayer-times and the qibla in the treatises on folk astronomy of Ibn Raḥīq (Mecca, 11th (?) century), al-Aṣbaḥī (Janad, 13th century) and al-Fārisī (Aden, 13th century) (*MAY*, nos. 2.1, 5.1 and 6.1) has been completed and was submitted as a doctoral dissertation in February, 2005. See Schmidl, *Islamische volksastronomische Abhandlungen*, and also *eadem*, "Qibla und Winde".

Some non-Yemeni materials on mathematical astronomy preserved in Yemeni sources have also been studied:

- A list of 13 observations made in Qus and Alexandria reported in the *zīj* of the 13th-century Yemeni astronomer Muḥammad ibn Abī Bakr al-Kawāshī (*MAY*, no. 7): see now King & Gingerich, "Astronomical Observations from 13th-Century Egypt".
- The mathematical structure and the mode of compilation of a highly sophisticated lunar table has been explained with the help of another table preserved in the *Anthology* and a remark by al-Afḍal on its provenance (see King, "Lunar Equation Table", pp. 132 and 135).

Considerable research has been conducted in recent years on astronomical instrumentation (see King, "Instrument Website"). In particular, progress has been made on the history of astronomical instrumentation in the Yemen. One astrolabe made by the Sultan al-Ashraf (*MAY*, no. 8) in 690 H [= 1291] has been preserved for us and is now in the Metropolitan Museum of Art in New York. Also, his treatise on the construction of astrolabes, sundials, and the magnetic compass has been studied further.

- A detailed description of al-Ashraf's astrolabe, also drawing on his treatise on instrumentation, was published in 1985 and a slightly revised description constitutes the main body of this study.
- Another unsigned Rasulid Yemeni astrolabe preserved in the Institut du monde Arabe in Paris was published by Jeanne Mouliérac in 1989 and is described anew in **App. A1** of the present study.
- A third Yemeni astrolabe identified in the Scientific Instrument Collection of Harvard University and first studied properly in 2004. It, like the second piece mentioned above, displays Maghribi influence. Furthermore, it contains a spurious plate that can be attributed to al-Ashraf. A description is in **App. A2** of the present study.
- Al-Ashraf's treatise also contains the earliest description of a magnetic compass bowl in which the needle floats on water or some liquid. His text, together with a contemporaneous text from Cairo on a dry compass, is now published: see Schmidl, "Early Sources on the Compass".

In conclusion, much has been done on the history of Yemeni astronomy in the past 30 years, but not enough. There is still much more to be done, but the field is vast and the workers few indeed. al-Afḍal and his modern editors have contributed substantially to our endeavours.

Part XIVb

Some astronomical instruments from medieval Syria

To the memory of Louis Janin

DEDICATION,
ACKNOWLEDGEMENTS AND NOTES TO THIS VERSION

This study is dedicated to the memory of a man who was fascinated by instruments and who knew their language. Louis Janin (1897-1978) spent his carrier in international commerce, being the director of a large Parisian bank, and working in Algeria for many years. Upon his retirement in 1965, he devoted his life to the study of the history of gnomonics, as his publications listed below attest. He was particularly interested in Islamic sundials.

I first met Louis Janin on paper the day before leaving Beirut for a visit to Damascus in the autumn of 1970. I was working in the library of Ted Kennedy and came across a preprint of an article by Janin that was to appear in the international journal of history of science, *Centaurus*, in 1972. The article "Le cadran solaire de Damas" (see below) was the first study of the spectacular sundial of Ibn al-Shāṭir. The next day I was in Damascus wondering at the sundial, or at least, at a late-19th-century copy of it. At the time I knew nothing about Islamic instruments, but here was a good one to start with. Janin had posed various questions in his study that demanded the intervention of an Arabist, so I wrote to him. Our collaboration, which started immediately and lasted several years, was a sheer joy to me. We eventually published a couple of papers together (see below). And my wife and I, with little Max, visited him at his *maison secondaire* in the Cévennes, little knowing that this area would eventually become our second home too.

The following list of Janin's publications is taken from an obituary published by his daughter, C. Nallet, the late René Rohr and myself, in *Journal of the History of Arabic Science* 3 (1979), pp. 85-87:

1969 "L'histoire du cadran solaire", *La Suisse horlogère* (1969), pp. 93-101.

1970 "Note sur le cadran solaire de Brou", *L'Astronomie* (Paris), 1970, pp. 83-85.
"Les cadrans solaires polyédriques du musée du Pays Vaurais", *Bulletin de la Société des Sciences, Arts et Belles-Lettres du Tarn*, N. S., 29 (1970), pp. 357-365.

1971 "Les méridiennes du château de Versailles", *Revue de l'Histoire de Versailles* 59 (1971).
"Un cadran solaire astronomique", *L'Astronomie* (Paris, 1971, pp. 251-259.

1972 "Le cadran polyédrique du cloître de Brou", *Bulletin de la Société des Naturalistes et Archéologues de l'Ain* (Bourg-en-Bresse, F) no. 86 (1972), pp. 77-82.
"Le cadran aux étoiles", *Orion* (Schaffhausen, CH), 30 (1972), pp. 171-175.
"Un cadran solaire de hauteur", *Sefunim* (Haifa) 4(1972-1975), pp. 60-63.
"Le cadran solaire de la mosquée Umayyade à Damas", *Centaurus* 16 (1972), pp. 285-298, repr. in E. S. Kennedy, and I. Ghanem, eds., *The Life and Work of Ibn al-Shāṭir: an Arab Astronomer of the Fourteenth Century*, Aleppo: Institute for the History of Arabic Science, 1976, pp. 107-121.

1973 "Le monument solaire de Bagneux", *Histoire archéologique—Bulletin de l'Association des Amis de Bagneux* (Bagneux, F), 1973, pp. 521-529.

1974 "Le cadran solaire multiface de l'Abbaye Sainte-Croix de Bordeaux", *Revue historique de Bordeaux et du département de la Gironde* 1974, pp. 31-41.
"Le cadran solaire analématique, histoire et développement", *Centre Technique de l'Industrie Horlogère*, (Besançon, F), no. 74.2057, (1974), pp. 1-37.
"Le cadran lunaire", *Orion* (Schaffhausen, CH) 32 (1974), pp. 3-11.
1975 "Un cadran solaire oublié", *Orion* (Schaffhausen, CH) 33 (1975), pp. 179-182.
"Deux astrolabes-quadrants turcs" (together with René R. J. Rohr,), *Centaurus* 19 (1975), pp. 108-124.
1976 "Un cadran solaire juif", *Centaurus* 19 (1976), pp. 264-272.
"Un compendium de poche par Humphrey Cole (1557)", *Annali dell'Istituto e Museo di Storia della Scienza di Firenze* 1 (1976), pp. 1-11.
1977 "Quelques aspects récents de la gnomonique tunisienne", *Revue de l'Occident Musulman et de la Méditerranée* (Aix-en-Provence, F), 1977, pp. 207-221.
"Un cadran de hauteur", *Annali dell'Istituto e Museo di Storia della Scienza di Firenze* 2 (1977), pp. 21-25.
"Ibn al-Shāṭir's Ṣandūq al-Yawāqīt: An Astronomical Compendium" (together with David A. King), *Journal for the History of Arabic Science* 1 (1977), pp. 187-256, repr. in King, *Islamic Astronomical Instruments*, London: Variorum, 1987, repr. Aldershot: Variorum, 1995, XII.
1978 "Un cadran solaire grec à Aï Khanoum, Afghanistan", *L'Astronomie* (Paris) 92 (1978), pp. 357-362.
"Le cadran solaire de la Mosquée d'Ibn Ṭūlūn au Caire" (together with David A. King), *Journal for the History of Arabic Science* 2 (1978), pp. 331-357, repr. in King, *Islamic Astronomical Instruments*, London: Variorum, 1987, repr. Aldershot: Variorum, 1995, XVI.
"Un texte d'ar-Rudani sur l'astrolabe sphérique", *Annali dell'Istituto e Museo di Storia della Scienza di Firenze* 3 (1978), pp. 71-75.
1979 "Astrolabe et cadran solaire en projection stéréographique horizontale", *Centaurus* 22 (1979), pp. 298-314.

The following descriptions of various Syrian instruments were prepared for the spectacular exhibition on all aspects of the history of Syria, held at the Institut du Monde Arabe in Paris from September, 1993, to February, 1994. The organizers, especially Jeanne Mouliérac, kindly asked me to choose some of the most significant Syrian astronomical instruments, and then took the trouble to secure them for the Exhibition. My descriptions were first published in French as "L'astronomie en Syrie à l'époque islamique", in *Syrie—mémoire et civilisation* (here referred to as *Paris IMA 1993-94 Exhibition Catalogue*,), Sophie Cluzan, Eric Delpont and Jeanne Mouliérac, eds., Paris: Institut du Monde Arabe, 1993, pp. 386-395, 432-443, and 480. The original version also contained a description of the Istanbul astrolabe of al-Baʿlabakkī, but that piece could not be liberated for the Exhibition from the Deniz Müzesi: I have since published a more detailed description, which is presented here as **XIIIc**. Also, the astronomical tables of al-Khalīlī in the magnificent Paris copy were described and displayed, and the reader

can now find a more detailed description in **II-10.2**. I had also suggested to the organizers that they include the Escorial manuscript of the astronomical handbook of al-Battānī and the Oxford manuscript of Ibn al-Shāṭir's treatise on planetary astronomy. The sundial of Ibn al-Shāṭir could not be displayed at the Exhibition because the Syrian authorities had supplied a copy, apparently in cement, that could not be moved. I had asked for copies in paper, such as were available from the Ministry of Surveying in Damascus during the 1970s. The reader will find below a description of the fate of this copy.

I have resisted the temptation to include here more information on the splendid astrolabe of Ibn al-Sarrāj (**5**). For this the reader must await the forthcoming monograph listed as Charette & King, *The Universal Astrolabe of Ibn al-Sarrāj*, which contains a more detailed description of the instrument and text, translation and commentary for a treatise by Ibn al-Sarrāj on a simple universal astrolabe and a treatise by al-Wafāʾī on this very instrument. I have also refrained from including an account of Ibn al-Shāṭir's compendium, and for this must refer the reader to my joint article with Louis Janin (see above); on this see also **X-9.3**. The description of the astrolabic plate of al-Wadāʿī (**3**) is taken from my *Islamic Astronomical Instruments*, London: Variorum, 1987, VIII. I have also inserted the description of the astrolabe in the tradition of al-Mizzī (**7**) and the astrolabic plate with markings for eight latitudes (**7***) from my unpublished instrument catalogue. My original description of the ceramic compass bowl from Damascus (**9**) was incomplete because I had not examined it closely. The description here is much more detailed, and has been supplemented by information in my *World-Maps for Finding the Direction and Distance to Mecca*, Leiden: E. J. Brill, and London: al-Furqān Islamic Heritage Foundation, 1999, pp. 110-114, 168-170, and 478-480. The description of the quadrant of Muḥammad al-Ṣakāṣī al-Jarkasī (**10**) is taken from a text prepared for *Christie's London 13.12.1996 Catalogue*, pp. 40-41 (lot 599). In the original version of this study I included an essay on the history of astronomy in Syria, the early sections of which have here been suppressed. The reader should be aware that **many important Syrian instruments are not included here**. I do not describe, for example: the spectacular astrolabe and mater of ʿAbd al-Karīm al-Miṣrī; the compendium of Ibn al-Shāṭir; various 14th-century quadrants, some by al-Mizzī; several universal plates (*ṣafīḥa*s); and others. These are listed, albeit together with Ayyubid and Mamluk instruments from Egypt, in Sections 1.5 and 3.2 and 4.3 of **XVIII**.

It was intended by the organizers that the Exhibition should also be held in Syria, but, for various reasons, this never happened. In any case, the Syrian public was denied access to the first major exhibition on their cultural heritage.

TABLE OF CONTENTS:

0 Astronomical instrumentation in Syria in the 13th and 14th centuries

> "Not one Mamluk astrolabe other than the universal instrument of Ibn al-Sarrāj is known to survive." D. A. King, "The Astronomy of the Mamluks" (1983), p. 545. [I cannot remember writing this absurd remark.]

Developments in astronomy in the 13th century

Damascus seems to have been an active centre of astronomy already in the 12th and 13th centuries. The biographical dictionaries of that period list several recent and contemporaneous scholars concerned with the sciences, mainly in Damascus.[1] Unfortunately for us, they were more involved in teaching than in writing treatises; in many cases, we have no information other than the fact that they were involved in science. This activity took place in spite of the scourge of the Crusades from the 11th to the 13th century and the Black Death in the 14th. Two Syrian instruments survive from the 12th century, first a small vertical sundial and second a most unusual astrolabe—see items **1** and **2**. The former is clearly related to the instrument tradition of ʿAbbāsid Baghdad; the latter in its artistic design bears no relation to any other known Islamic astrolabe, and, as we shall see, from a scientific point of view, is rather problematic.

Remarkable developments in planetary astronomy and the new models for the sun, moon and planets proposed by the astronomers at Maragha in N. W. Iran during the latter half of the 13th century. A Syrian astronomer was involved with the programme there, namely, Muʾayyad al-Dīn al-ʿUrḍī. A Maghribi astronomer Muḥyi 'l-Dīn al-Maghribī compiled a *zīj* for Damascus before joining the Maragha team. Even the astronomer-prince Abu 'l-Fidāʾ of Hama, well known for his interest in geography, was involved with astronomy; he appears to have authored a *zīj*, which, unlike the works of al-ʿUrḍī and al-Maghribī, is no longer extant.

The monumental astrolabes of ʿAbd al-Karīm al-Miṣrī and al-Baʿlabakkī

It has not been stressed previously that two magnificent 13th-century astrolabes in London and Oxford that are signed by one ʿAbd al-Karīm al-Miṣrī were made in Syria. The London piece has a spectacular zoomorphic rete: see **Fig. X-1.4**, and the Oxford piece now sports a replacement rete from Central Asia: see **Fig. XIV-2.1a**. These two astrolabes remain to be properly published, and I shall refrain from discussing them in any detail here. There are still some unresolved problems relating to their inscriptions, especially on the London one, which has been tampered with. In any case, their Syrian provenance is clear from the fact that neither contains a plate for Cairo.

Only recently have we come to know that a third such astrolabe, albeit with a far less ornate rete, survives: this is the monumental astrolabe by al-Baʿlabakkī that I discuss in **XIVc**. We have no information on the cultural or scientific context of these remarkable instruments.

Standard astrolabes were also produced at the same time. We have three from the hand of al-Sirāj, a muezzin in Damascus in the early 13th century (see also **XIVc-0**).

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[1] On the context see King, "The Astronomy of the Mamluks", and, on the defexts of that study and a challenge to future researchers, see *idem*, "Reflections", pp. 54-55.

The influence of al-Marrākushī and the Egyptian tradition
A revival of astronomy in Egypt in the 13th century was influential in Syria. About 1280 the Cairo astronomer Abū ʿAlī al-Marrākushī compiled a *summa* of spherical astronomy and instruments, mainly from earlier sources but also adding material of his own that was mainly in the form of numerical examples and tables specifically computed for the latitude of Cairo (**II-2.7**). This work set the tone of astronomical timekeeping for several centuries. The treatise, appropriately entitled *Jāmiʿ al-mabādiʾ wa-l-ghāyāt fī ʿilm al-mīqāt* (= *An A to Z of Astronomical Timekeeping*), was first studied in the West in the 19th century. Of great historical interest is the treatise by al-Marrākushī's late contemporary, Najm al-Dīn al-Miṣrī, who described and illustrated over one hundred different instrument types, many devised by himself. This treatise was apparently without influence, for no references to it or materials from it are known from later Egyptian or Syrian sources.

At about the same time a contemporary of al-Marrākushī, Shihāb al-Dīn Aḥmad ibn ʿUmar al-Maqsī, compiled a set of tables, probably based on earlier tables by the 10th-century astronomer Ibn Yūnus, displaying the time since sunrise as a function of solar altitude and longitude for the latitude of Cairo. In the 14th century, this set was expanded and developed into a corpus of tables covering some 200 manuscript folios and containing over 30,000 entries. The Cairo corpus of tables for timekeeping was used for several centuries and survives in numerous copies, no two of which contain exactly the same tables (**II-4-5**). The bulk of the corpus is made up of tables displaying the time since sunrise, the hour-angle (the time remaining until midday), and the solar azimuth for each degree of solar altitude and each degree of solar longitude. There are other tables displaying the solar altitude and hour angle at the *ʿaṣr*, the solar altitude and hour-angle when the sun is in the direction of the *qibla*, and the duration of morning and evening twilight. These tables inspired the later ones for Damascus by al-Mizzī and al-Khalīlī—see **II-9.2** and **10**.

The solitary instrument specialist of Aleppo, Ibn al-Sarrāj
The early-14th-century Aleppo astronomer Shihāb al-Dīn Aḥmad ibn Abī Bakr known as Ibn al-Sarrāj was the leading instrument-maker of the late medieval period. Little is known about him other than that he worked in Aleppo and that he was not associated with any mosque or madrasa. Happily, his major production has survived intact and was on loan to the Paris exhibition (**5**). The instrument has been known since the 1930s but only recently studied in detail. Without any shadow of a doubt, it is the most sophisticated astronomical instrument made anywhere in the world between Antiquity and the 17th century.

Ibn al-Sarrāj's astrolabe is quintuply-universal, that is, it can be used for any terrestrial latitude in any of five different ways. It represents the culmination of the Eastern Islamic tradition of astrolabes with a universal plate of horizons and quadrants of astrolabic markings and trigonometric grids, and the Western Islamic tradition of the universal astrolabe and the universal plate known as the *shakkāziyya*. Mamluk astronomers were aware of the achievements of Eastern Islamic instrumentation, and also of the single universal plate of the 11th-century Andalusī astronomer Ibn al-Zarqālluh, which is known to have been transmitted eastwards. There is, on the other hand, no evidence that Ibn al-Sarrāj knew of the simpler variety of

universal astrolabe—by no means simple, but, rather, already highly sophisticated—that had been invented in al-Andalus in the 11th century by Ibn al-Zarqālluh's contemporary ʿAlī ibn Khalaf (**X-5.1**).

In other words, Ibn al-Sarrāj reinvented the universal astrolabe. He claims this in a short treatise in which he describes the simpler form of universal astrolabe, with a universal plate and a rete consisting of a half-circle of universal markings and a half-circle including a complete ecliptic and star-pointers. This treatise was clearly compiled before he invented his quintuply-universal astrolabe. This instrument was first seriously studied in the early 1970s, and at that time it was by no means clear how all of the various components were expected to function. Then in 1975 a treatise was identified written by al-Wafāʾī, a 15th-century Egyptian astronomer who had owned this very instrument. al-Wafāʾī complained that Ibn al-Sarrāj had not written a treatise to explain the various operations that one can perform with the instrument and undertook to do this himself. Fortunately he was equal to the task, for his treatise contains all of the answers to our remaining questions about how to use it, though not how Ibn al-Sarrāj was able to conceive it or how he constructed it.

Astronomy in Damascus in the 14th century

Damascus was home to a particularly vigorous tradition of astronomy in the 14th century, centred on the Umayyad Mosque in the heart of the city. This tradition was but one of many colourful aspects of life under the Mamluks, who ruled Egypt, Syria, Palestine and the Hejaz from the mid 13th to the early 16th century. A team of *muwaqqit*s was employed at the Mosque, but the interests of some of them extended far beyond *ʿilm al-mīqāt*. We shall discuss the three main representatives of this team. But first we should mention instrument-making in 13th-century Syria, as well as a 14th-century *mīqātī* of consequence from Aleppo, whose works on instruments inspired the Damascus *muwaqqit*s.

al-Mizzī, famous for his instruments

Shams al-Dīn Muḥammad ibn Aḥmad ibn ʿAbd al-Raḥīm al-Mizzī was a contemporary of Ibn al-Sarrāj. He was born in 690 H [= 1291], studied in Cairo under Ibn al-Akfānī, and then worked as a *muwaqqit* at the Umayyad Mosque. He is known as the compiler of tables for timekeeping by the sun with some 10,000 entries and others for determining the times of prayer, modelled on those he had seen in Cairo but now computed for the latitude of Damascus, taken as 33;27° (with obliquity of the ecliptic 23;33°) (see now **I-2.1.3** and **II-9.2**), as well as the author of various treatises, mainly on the use of different varieties of quadrants. He was famed for his instruments: his quadrants are reported to have sold for 2 *dīnār*s, his astrolabes for 10. It is remarkable that in addition to one astrolabic plate and one astrolabe apparently copied from one of his (**7**), four quadrants by him other than the one discussed below (**6**) have survived. al-Mizzī died in Damascus in 750 H [= 1349].

Ibn al-Shāṭir and the culmination of Islamic planetary astronomy

The chief *muwaqqit* at the Umayyad Mosque during the 1360s and 1370s was ʿAlāʾ al-Dīn ʿAlī ibn Ibrāhīm called Ibn al-Shāṭir, known today for his innovative and successful research

on geometric models for the sun, moon and planets. Like al-Mizzī, he studied astronomy in Egypt, but—as we shall see—his major achievements were inspired by a very different astronomical tradition, namely, that of Maragha.

Ibn al-Shāṭir compiled some prayer-tables for an unspecified locality with latitude 34° (possibly the new Mamluk city of Tripoli) and obliquity 23;31° (**II-9.3**). He also invented various instruments and authored treatises on their use. One of these was a compendium in the form of a box, the lid of which could be raised to serve the astronomical function of the box and its appendages for any of a series of terrestrial latitudes (**X-9.3**). This lid bears a set of astrolabic horizon markings, and a removable plate inside the box bears a universal polar sundial and a set of qibla-markers for different localities. All of the other parts of this compendium, which are missing from the only surviving specimen of it now preserved in Aleppo, such as a magnetic compass for aligning the instrument in the cardinal directions and the sights for reading the time from an equatorial scale on the lid of the box, are described in a treatise on its use, preserved in Berlin and authored by Ibn al-Shāṭir himself.

An astrolabe that seems to be an early work of Ibn al-Shāṭir is presented here (**4**). The contemporary historian al-Ṣafadī reports seeing a monumental astrolabic clock in Ibn al-Shāṭir's house. In 1371 the Damascene astronomer constructed the splendid sundial that was installed on the main minaret of the Umayyad Mosque, where a copy of it made in the 19th century remains to this day (**8**). This is the most sophisticated sundial made before the European Renaissance.

In addition to this work on timekeeping, Ibn al-Shāṭir concerned himself with theoretical astronomy, thereby incorporating the results of the Maragha astronomers into the Damascus programme.[2] Alas, no copy of the book in which Ibn al-Shāṭir's *Taʿlīq al-arṣād*, "Discourse on Observations", has come down to us. But we should be grateful that the *Nihāyat al-suʾl* is available and we await with anticipation the forthcoming edition, translation and commentary by George Saliba. In this work Ibn al-Shāṭir "laid down the details of what he considered to be a true theoretical formulation of a set of planetary models describing planetary motions, and actually intended as alternatives to the Ptolemaic models" (Saliba). In his *zīj* for Damascus called *al-Zīj al-jadīd*, "The New Astronomical Tables", which survives in several copies, he actually computed new solar, lunar and planetary tables based on these models.

Ibn al-Shāṭir died between 1375 and 1380 (the sources differ on the exact year). He is one of the few astronomers of this period to be mentioned in contemporary biographical sources.

al-Khalīlī and the culmination of astronomical timekeeping

Biographical information on Shams al-Dīn Abū ʿAbdallāh Muḥammad ibn Muḥammad ibn Muḥammad al-Khalīlī, a man only recently recognized for his remarkable competence in computation, is scant indeed, although the epithet al-Khalīlī indicates that his family came from Hebron in Palestine. In his first set of tables, completed in 763 H [= 1361], he is referred to

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[2] See the remarks in **I-2.1.4**, n. 15.

as a *muwaqqit* at the Yilbughā Mosque, a new mosque in Damascus established by the Governor Sayf al-Dīn Yilbughā in 747 H [= 1346]. But in copies of his main corpus he is referred to as a muezzin or a *muwaqqit* at the Umayyad Mosque.

al-Khalīlī recomputed al-Mizzī's tables for the new parameters derived by Ibn al-Shāṭir in 765 H [= 1363/64], namely: 33;30° for the latitude of Damascus and 23;31° for the obliquity of the ecliptic. His corpus of tables for solar timekeeping and the regulation of the times of prayer for Damascus continued to be used in one form or another until the 19th century. In addition, al-Khalīlī prepared a set of auxiliary tables for solving the standard problems of spherical astronomy for all latitudes, as well as a universal qibla-table. al-Khalīlī's tables survive in about three dozen manuscripts, of which few are complete. Fortunately, the best copy is complete and could be displayed at the Paris exhibition. See further **II-10.2**.

Astronomy in Syria after the 14th century

Not all creative scientific activity in Syria came to an end with the destruction of Damascus by the Mongols in 1402. About 1425 Shihāb al-Dīn al-Ḥalabī compiled some new tables for timekeeping for Damascus to supplement those of al-Khalīlī. About 75 years later al-Ṣāliḥī produced a Syrian recension of the *Zīj* of Ulugh Beg of Samarqand (*ca*. 1425). And about 1650 al-Qazwīnī prepared a recension of the *Zīj* of Ibn al-Shāṭir. Each of these men was a *muwaqqit* at the Umayyad Mosque in Damascus.

Although the *Zīj* of Ibn al-Shāṭir was based on his new models and was widely used at least in Syria and Egypt for several centuries, it has not yet been determined whether his tables were favoured because they were based on new models or simply because they were computed by him, a widely-renowned *muwaqqit*.

With the passage of time only al-Khalīlī's calendrical tables and the solar longitude table needed to be updated. The decreasing obliquity (23;30° observed *ca.* 1440 by Ulugh Beg and 23;29° used by later Ottoman astronomers) was not considered sufficient cause to recompute the corpus, or even the prayer-tables. Various later Syrian astronomers adapted al-Khalīlī's tables; improve them they could not.

Besides these modifications to al-Khalīlī's corpus, various new sets of prayer-tables were compiled for a variety of localities after the 14th century. Mention may be made of the anonymous prayer-tables for Tripoli, Istanbul, Aleppo, Mecca, and Lattakia. al-Khalīlī's main auxiliary tables were used for several centuries not only in Syria but also in Egypt, the Maghrib, and Turkey. al-Khalīlī's qibla-table was not widely used after his time, and no references to it have been found in treatises by any contemporary or later Muslim astronomers. On the other hand, his list of qiblas appears in several later Syrian and Egyptian manuscripts. Even so, the mathematically computed qibla values for various Syrian cities were not always taken seriously by those who built mosques. (In Syria early mosques faced the traditional qibla direction of due south, while later mosques are often oriented at variance to the directions that can be computed from medieval geographical coordinates. This is particularly evident in the new Mamluk city of Tripoli, where the religious architecture faces several different directions. The modern qibla value for Damascus (based on the correct longitude difference from Mecca) is

some 15° closer to south than al-Khalīlī's value, but this is irrelevant to any discussion of the orientation of medieval mosques.

The Ottoman Turks found themselves heirs to the Egyptian and Syrian traditions, as well as to the works of the Samarqand school of Ulugh Beg. The most important Muslim astronomer of the 16th century, Taqi 'l-Dīn ibn Maʿrūf, who directed the short-lived Observatory in Istanbul, was a Syrian who had lived in both Egypt and Palestine and was familiar with the rich heritage of Mamluk astronomy. In the 18th century the Ottomans came in contact with European astronomy and the "*Zīj*es" of Lalande and Cassini were translated into Turkish and their tables adapted to the longitude of Istanbul. Other versions were later prepared in Arabic for Damascus and Cairo.

Astronomy continued to be studied in Damascus and Aleppo, as well as in Cairo, after Istanbul had become the centre of astronomical activity in the Islamic world. Different and virtually independent schools continued to flourish in the Maghrib as well as in Iran and Muslim India. The preparation of annual ephemerides and the copying of tables for timekeeping continued apace. Where initiative appears, as on the splendid quadrant of Muḥammad al-Ṣakāsī, dated 1891/92, we are safe in assuming that the maker was copying from an earlier piece. The compilation of treatises on the construction and use of instruments continued until the 19th century, but there was nothing new in these after the 15th century. The great scientists of such calibre as Ḥabash, al-Battānī, Ibn al-Shāṭir, al-Khalīlī, had been virtually forgotten. Towards the end of the 19th century, al-Ṭanṭāwī, the last traditional *muwaqqit* at the Umayyad Mosque, converted all of splendid al-Khalīlī's tables so that the entries were in Turkish time (with sunset as 12 o'clock) and made a copy of Ibn al-Shāṭir's spectacular sundial. Shortly thereafter Carlo Alfonso Nallino edited the *Zīj* of al-Battānī, and a new era had begun.

1 A vertical sundial of the "locust's leg" variety, signed by Abu 'l-Faraj ʿĪsā and dated 1159

International Instrument Checklist #7315.
Paris, Bibliothèque Nationale de France, Département des Monnaies, Médailles et Antiques, inv. no. F. 6909. Purchased in 1895 at the suggestion of Paul Casanova from M. Durighello of Beirut, who had acquired it from M. Darricarrère, a French businessman of the same city.
Brass. Length: 86 mm. Width: 51 mm.
Bibliography: Casanova, "Cadran solaire syrien" (detailed description); Mayer, *Islamic Astrolabists*, pp. 52-53 (with additional references); *Paris BN 1981 Catalogue*, p. 3 (no. 3); *Paris IMA 1993-94 Exhibition Catalogue*, pp. 436-437 (no. 332); and **IV-7.4**.

This is a vertical sundial for measuring the time of day in seasonal hours—one-twelfth divisions of the length of daylight—throughout the year. The markings are similar on each side, those on the front, which bears the longest inscription, serving 36° [= Aleppo], and those on the back 33° [= Damascus]. The inscription on the front translates:

لملك العادل نور الدين محمود بن زنكي | لمعرفة الساعات الزمانية وأوقات الصلوات | لعرض لو
صنعة أبي الفرج عيسى تلميذ القسم | بن هبة الله الأصطرلابي سنة ثند

a

b

Fig. 1a-b: The front and back of Abu 'l-Faraj's sundial (#7315). [Courtesy of the Bibliothèque Nationale de France.]

"(For ? / By order of ?) the just king Nūr al-Dīn Maḥmūd ibn Zankī, for finding the seasonal hours and the times of prayers for latitude of 36°, constructed by Abu 'l-Faraj ʿĪsā, student of al-Qāsim ibn Hibatallāh al-Aṣṭurlābī, in the year 554 (Hijra) [= 1159/60]."

and that on the back:

معرفة الساعات الزمانية لعرض لج

"(For) finding the seasonal hours for latitude 33°."

The maker is otherwise unknown, but Hibatallāh, the father of his teacher, was a well-known instrument-maker of Baghdad, some of whose pieces survive.[3] Nūr al-Dīn (born 1118, died 1174) was the Atabeg ruler first of Aleppo, later also of Damascus and Egypt.

The gnomon, or device for casting a shadow on the markings on the sundial, is missing. It was intended to be fitted in the holes corresponding to each pair of zodiacal signs with the same solar declination, whose names are engraved on the scale at the bottom: it may have been divided across its width for each 5° of solar longitude. Certainly, the main markings are divided by longitude lines for each 5°. These run from left to right between the winter solstice, when the midday vertical shadows are shortest to the summer solstice, when they are longest. The markings for the hours cross these, the lowest serving midday, when the shadows are longest, and the horizontal one at the top serving sunrise or sunset, when the shadow-length is zero.

Most significant is the fact that there are no separate markings for the prayers, that is, for the *ẓuhr* and the *ʿaṣr*. This is evidence that they were to be regulated at the seasonal hours, either at the beginning of the 7th or 8th hour for the former, and most probably at the beginning of the 10th hour for the latter. The standard definitions of the times of prayer in terms of shadow increases, which were first introduced in the law books of the 8th century, are practical means of regulating the prayer in terms of the seasonal hours. Thus, for example, an increase of the shadow equal to the length of the gnomon indicates the end of the 9th hour or beginning of the 10th, that is, mid-afternoon. al-Bīrūnī mentions people who used the seasonal hour curves on astrolabes to regulate the day-light prayers; this sundial provides more evidence of the same practice. See further **IV-7.4**.

In a brilliant account of this instrument, Paul Casanova related it to the same kind of instrument as described by the Cairo astronomer Abū ʿAlī al-Marrākushī *ca*. 1280 in his monumental treatise on instruments. Here it is called *sāq al-jarāda*, locust's leg, because of the general appearance of the markings, and al-Marrākushī provides a table for constructing the hour-curves for the latitude of Cairo. This is, in fact, one of several instruments devised by Muslim astronomers in 9th-century Baghdad, on which research has only recently begun. As pointed out by Casanova, such sundials, albeit with less accurate markings, are also known from Antiquity.

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[3] On Hibatallāh see Rosenthal, "Al-Asṭurlābī and as-Samawʾal on Scientific Progress", and for one of his instruments, see King, "*Zīj al-Ṣafāʾiḥ*".

2 An astrolabe with a rete decorated with circus figures by al-Sahl al-Nīsābūrī datable to *ca*. 1180-1280

International Instrument Checklist #137.
Nuremberg, Germanisches Nationalmuseum, inv. no. WI 20. The instrument appears to have been in Nuremberg since the 15th century and may have been part of the collection of Regiomontanus.
Brass, with silver plating on the rete and silver inlay on the throne and back. Diameter: 161 mm. Height: 255 mm. Thickness: 6 mm. Length of pin: 30 mm.
Bibliography: The earliest writings on this instrument are listed in the latest Nuremberg catalogue (see below). In Gunther, *Astrolabes*, I, pp. 280-281 (no. 137), this astrolabe, listed amongst Moorish instruments (!!), was dated to the 12th century but was confused with a European astrolabe dated 1468 and falsely attributed to Regiomontanus; the Syrian piece is in fact not featured at all by Gunther. Numerous references are provided in Mayer, *Islamic Astrolabists*, pp. 82-83. Illustrations and brief descriptions are featured in Zinner, *Regiomontanus*, p. 222 (where this instrument is again confused with another one) and pl. 42, figs. 80-81; *Nuremberg 1983 Catalogue*, pp. 33-35 (no. 2), with illustrations of the front on p. 35 and a blow-up of the rete on the front and back covers, all in splendid colour; King, "Strumentazione", p. 160. An unpublished study of the rete from the point of view of an art historian is in Kolbas, "The al-Sahl Astrolabe"; here alone (pp. 50-52) is the symbolism of the figures on the rete discussed. Gingerich, "Zoomorphic Astrolabes", p. 97, provides an astronomical identification of the thirteen figures. Detailed descriptions by the present author are in *Nuremberg 1992-93 Exhibition Catalogue*, I, p. 110 (on the Regiomontanus connection), and II, pp. 570-574 (no. 1.71), and *Paris IMA 1993-94 Exhibition Catalogue*, pp. 432-434 (no. 329). On the star-positions see Stautz, *Mathematisch-astronomische Darstellungen auf mittelalterlichen Instrumenten*, pp. 66-67 and 205-207. On a facsimile of sorts see Sezgin & Neubauer, *Wissenschaft und Technik im Islam*, II, p. 104.

This unusual and singularly elegant astrolabe is said to have once belonged to Regiomontanus, the leading European astronomer of the 15th century.[4] Certainly, it passed from Syria through Italy in the late Middle Ages, but it is not known precisely how or when it came to the Stadtbibliothek in Nuremberg, whence it was passed to the Museum in 1877. Unfortunately, the astrolabe is undated, and it could date from *ca*. 580 H as well as from *ca*. 680 H, that is about 1180 or 1280.

The throne is elegantly decorated on both sides with a complicated foliate design. Across the base of the throne at the front is an inscription in heavy *kūfī* script:

عمل برسم خزانة الملك المظفر تقي الدين

"Made (*ʿumila*) by order of the Treasury (*khizāna*) of
al-Malik al-Muẓaffar Taqi 'l-Dīn,"

and on the base of the back of the throne is the inscription:

صنعه السهل الأصطرلابي النيسابوري

[4] See *Nuremberg GNM 1992-93 Exhibition Catalogue*, I, p. 110. In Sezgin & Neubauer, *Wissenschaft und Technik im Islam*, II, p. 104, it becomes Regiomontanus himself who inserted the replacement plates.

a

Figs. 2a-b: The front and back of the astrolabe of al-Sahl al-Nīsābūrī (#137). [Courtesy of the Germanisches Nationalmuseum, Nuremberg.]

b

"Constructed by al-Sahl al-Aṣṭurlābī al-Nīsabūrī."

It is clear that the dedication refers to one of the Ayyubid princes of Hama, but, unfortunately, there were three princes of that city (the second being the grandson of the first and the third the grandson of the second) who held the title al-Malik al-Muẓaffar Taqi 'l-Dīn, namely:

ʿUmar, *reg*. 574 H [= 1178/79] until his death in 587 H [= 1191];

Maḥmūd, *reg*. 626-642 H [= 1228/29-1244/45]; and

Maḥmūd, *reg*. from 683 H [=1284/85] until his death in 698 H [= 1299].[5]

It is not possible to say definitively which one was intended in the inscription; however, if the second or third was intended the maker might have thought it necessary to identify him more carefully to distinguish him from his grandfather or great-great-grandfather. L. A. Mayer did not question an association with the third of these rulers; Judith Kolbas, on the other hand, opted for the second because of his known interest in astronomy. Fuat Sezgin makes one person out of the second and third. The maker is otherwise unknown to us.

The two dozen surviving astrolabes made in Egypt, Syria and the Yemen in the 13th and 14th centuries represent the most colourful and innovative of any regional tradition (Islamic or European), and al-Sahl's astrolabe is in one sense a good example. However, as we shall see, it is, from an astronomical and practical point of view, completely non-functional. In this it is unique amongst early Islamic instruments, which are characterized by the accuracy of their markings. (In the case of the earliest surviving Islamic astrolabe, discussed in **XIIIb**, the positions *were* accurate for the epoch, if only according to contemporaneous astronomical knowledge.)

Both the front and back of the throne are decorated with elegant floriated designs inlaid in silver. The suspensory apparatus appears to be original. The scale of the rim is divided for each degree and labelled for each 5° in simple *kūfī* script.

The spectacular rete is the most original feature; indeed, it is unique in Islamic instrumentation, since some constellation figures are depicted as well as individual stars. The figures are those of a circus troupe of acrobats or jugglers such as occur on contemporary pottery from Syria. Judith Kolbas pointed to the popularity of the shadow play in this region in the 12th century, seeing the figures on the rete as puppets for such a play. The figures, of which the first and third do not correspond to any constellation figure, and the tenth is apparently merely a symbol for the star *al-wāqiʿ* (Vega), are as follows:

juggler 1	Cassiopeia
juggler 2	-
juggler 3	Orion
juggler 4	-

[5] Bosworth, *Islamic Dynasties*, new edn., pp. 71-72.

lion	Leo
bird 1	Corvus
juggler 5 (holding end of lance)	Boötes
juggler 6 (holding middle of lance)	Hercules
juggler 7 (holding serpent)	Ophiuchus
snake (dangling)	Serpens
bird 2	symbol for Vega
bird 3 (swooping)	Aquila
horse (winged)	Pegasus

The associated constellations are actually named, explicitly or implicitly, on the star-pointers. There are 21 standard stars with 20 associated names:

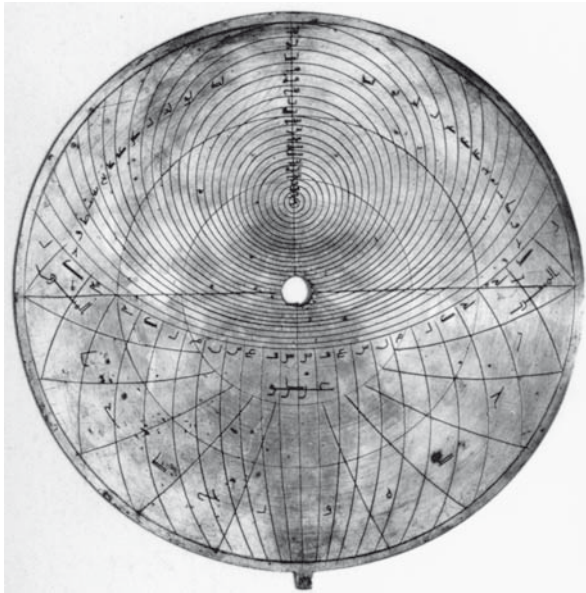
dhāt al-kursī	hair of juggler 1
al-khaḍīb	finger of juggler 1
raʾs al-ghūl	cap of juggler 1
*al-dabarān**	end of finger of juggler 2
[*al-ʿayyūq*]	unnamed triangular pointer on central disc
rijl al-jawzāʾ	leg of juggler 3
yad al-jawzāʾ	hand of juggler 3
shiʿrā al-yamāniya	fold on upper sleeve of shirt of juggler 3
al-shaʾāmiya	hat of juggler 4
qalb al-asad	paw of lion (on ecliptic)
janāḥ al-ghurāb	bump on breast of bird 1
al-simāk al-rāmiḥ	codpiece of juggler 5
qalb al-ʿaqrab	protrusion on circumferential frame
al-jāthī	hat of juggler 6
al-ḥawwāʾ	hand of juggler 7
ḥayyat al-ḥawwāʾ	snake—exact position of pointer ??
al-wāqiʿ	beak of bird 2
al-ṭāʾir	beak of bird 3
fam	below belly of horse (!)
mankib	wing of horse
fam al-faras	"tail" of horse (note that *fam* is repeated)

* An additional phrase on this pointer refers to astrological qualities of the star.

Investigations by Burkhard Stautz of the star-positions on the rete show that they correspond to *ca*. 600±100, that is, to positions that might have been used before the new observations in Baghdad established that the Ptolemaic value for precession was incorrect. They were clearly based on an early source in the *Almagest* tradition, perhaps calculated from one of the earliest Arabic translations of the *Almagest* or copied from an older Greek Byzantine globe. It is a complete mystery why the maker did not bother to use an updated star-list, of which several were available in Syria in his time.

Only two out of the four plates are original. These two bear altitude circles for each 3° and azimuth curves for each 10° below the horizon. They are of a high quality of workmanship and display interesting construction marks (see **Fig. XIIIa-3.1a**). The underlying latitudes are stated to be:

30°, 33°, 36°, 39°,

and places such as Cairo, Damascus, Aleppo would be served by the first three of these. One would have expected a plate with markings that would serve Hama, but the other two plates have additional markings by a European—see below. The mater bears four sets of half-horizons serving 19 latitudes between 10° and 52°.

c

d

Figs. 2c-d: (c) The plate for latitude 36° and (d) the mater of the astrolabe of al-Sahl al-Nīsābūrī (#137). [Courtesy of the Germanisches Nationalmuseum, Nuremberg.]

The back bears four altitude scales divided for each 1° and labelled for each 5°. These double as declination scales on the equatorial and ecliptic grids—the combination was known as the *shakkāziyya*—that fill the space within. The equatorial coordinates are shown for each 10° of both arguments. At an angle of $23^1/_2$° to these is a similar set of markings for the ecliptic inlaid in silver. The names of the signs are engraved in the *kūfī* of the inscriptions on the throne whereas all other inscriptions on the back are in ordinary *kūfī*. Some 50 stars are marked with black circles with silvered interiors, most of them being north of the ecliptic. Investigations of their positions by Burkhard Stautz indicate that they correspond to the same date as those on the rete. It is curious indeed that an astrolabist who was familiar with the latest trends in astrolabe construction (the grid had only recently been imported to Syria from al-Andalus) would not have taken the trouble to update the star-positions. Like the rete, the grid is astronomically useless.

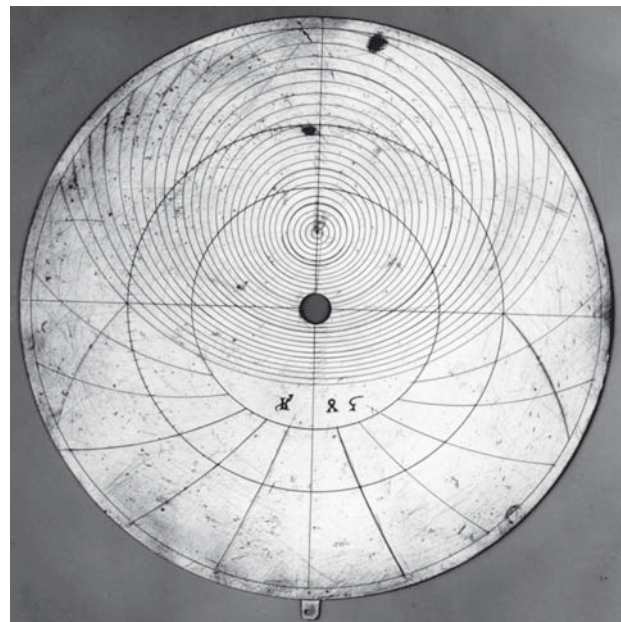
The alidade has markings corresponding to the divisions of the grid below it and also a perpendicular rule divided for each 5° of argument, as if to measure the altitude above the alidade used as a horizon. For the purposes for which the grid was intended, this perpendicular rule is not as useful as it would be if it could be moved transversely (as on the original alidades proposed by the Andalusī inventors of the instrument or on Renaissance European versions).

Later markings

One spurious plate has been engraved in a bold but fairly crude 14th- or 15th-century Gothic script with markings for latitudes 45° and 48°. There are curves for the prime vertical below the horizon (unusual), but otherwise no azimuth curves. This is not the work of Regiomontanus, for we have instruments associated with him that are much finer (see **Fig. XIIIa-10.6a-b**). The other later plate bears different markings, serving the astrological doctrine of casting the rays, for latitudes

e

f

Fig. 2e: (e) A detail of the back. [Photo by the author, courtesy of the Museum.]
Fig. 2f: The markings for latitude 45° one one of the two spurious plates in the astrolabe of al-Sahl al-Nīsābūrī (#137). [Courtesy of the Germanisches Nationalmuseum, Nuremberg.]

42° (incomplete) and 51° and inscriptions in a very faint early Renaissance script. These plates should be investigated further to see whether or not the metal is the same as that of the rest of the instrument.

3 A remarkable instrument probably from Syria and a later copy

The more one looks at instruments one does not really understand, the more one can learn. I had written descriptions of the following objects in 1984 and 1990, respectively, without even noticing their most significant feature, which came to light during my instrument seminar at Frankfurt University in May, 2004.

3.1 An astrolabic plate with myrtle markings on one side and a universal projection on the other, signed by ʿAlī al-Wadāʿī and datable *ca.* 1250

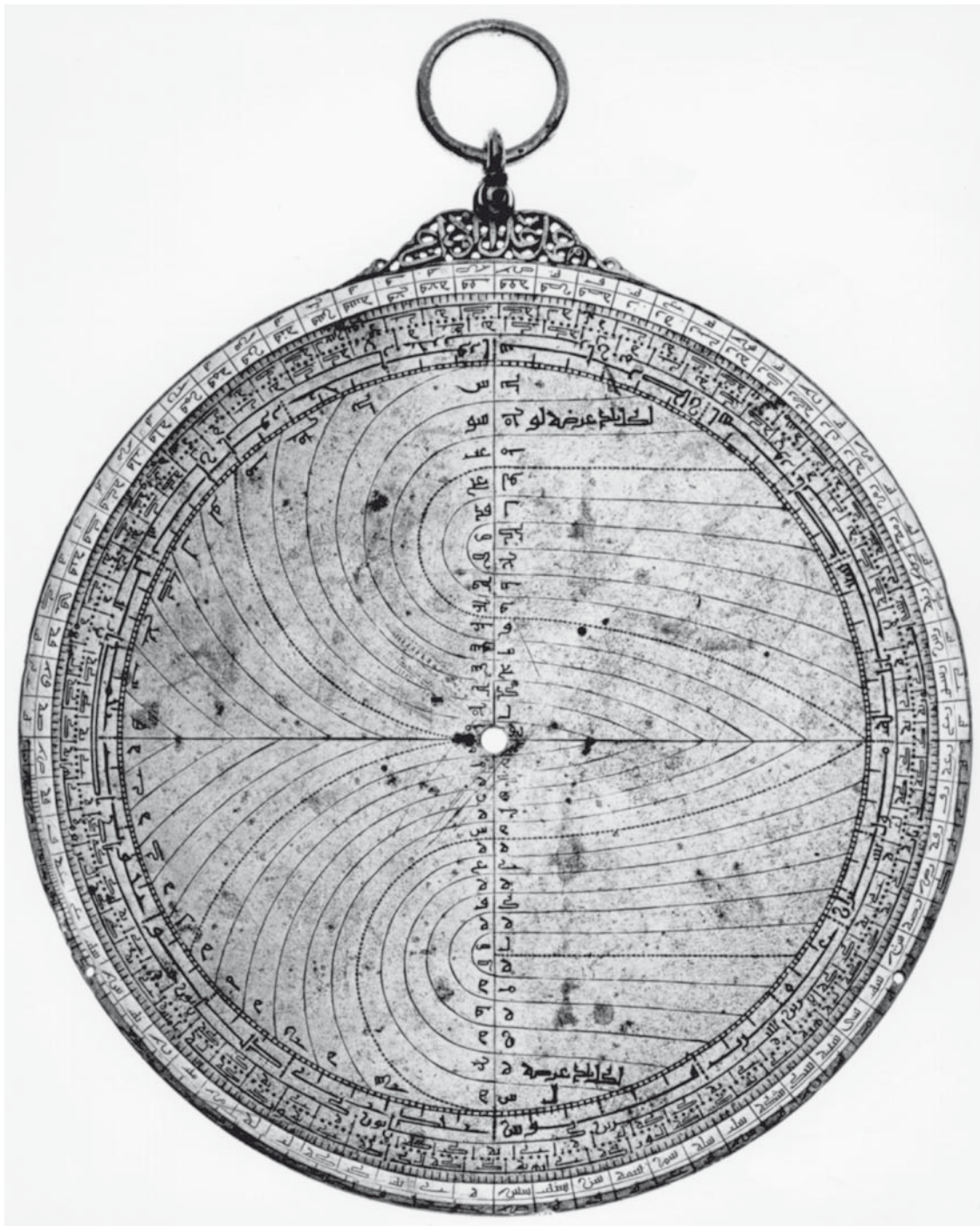
International Instrument Checklist #4026.
London, Ahuan Gallery. Until recently, Rockford, Ill., Time Museum, inv. no. 3529. Acquired at Sotheby's, London, 31.03.1978. Earlier provenance ??
Brass with silver inlay. Diameter: 17.0 cm.
Bibliography: *Rockford TM Catalogue*, I-1, pp. 168-173 (no. 22), by Anthony J. Turner and this author (misdated to 1375-1425); also King, "The Astrolabe of al-Wadāʿī", first published in *idem*, *Studies*, VIII.

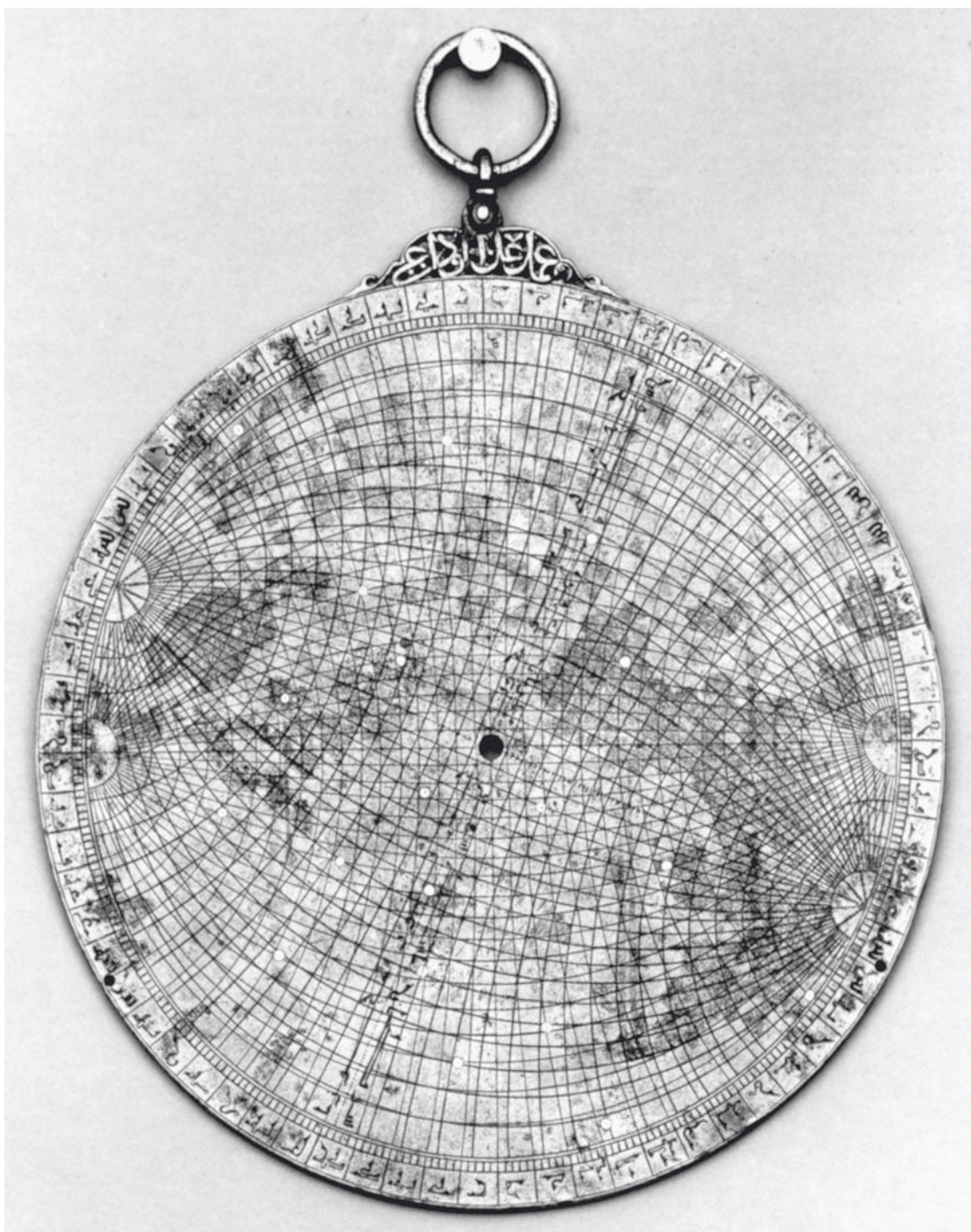
The instrument displayed in **Figs. 3.1a-b** is not dated but, by virtue of various features, it can be securely attributed to the 13th century. The inscription on the *kursī* is cunningly wrought so that the same text:

عمل علي الوداعي

can be read from either side, a kind of palindrome: see **Fig. 3.1c-d**. I am not aware of any other such palindrome in Islamic metalwork.[6] It identifies the maker as ʿAlī al-Wadāʿī, an individual whose name is new to the modern literature on medieval Islamic instrumentation. The name ʿAlī is written simply *ʿayn-lām*, that is, the final *yāʾ* is suppressed; this calligraphic feature is associated with a variety of script called *muʿammāʾ*.[7] The *nisba* al-Wadāʿī indicates

[6] Compare the ceremonial iron anchor from 16th-century Iran preserved in the Musée des arts décoratifs in Paris. Here an epigraph in elegant *muḥaqqaq* script is superposed on an arabesque pattern, neither element intruding on the other, and both set within a rectangular frame. See Melikian-Shirvani, *Le bronze Iranien*, p. 104, and Welch, *Calligraphy in the Arts of the Muslim World*, pp. 146-147 (no. 60). Again there is an openwork steel plaque from the door of a tomb from 17th-century Iran in The Art Institute of Chicago. Here a verse from the *Qurʾān* is written in elgant *thuluth* script over a delicate background of arabesques. See Welch, *op. cit*., p. 145 (no. 59). Finally, I mention a similar kind of inscription in quatrefoil frames as well as a remarkable pierced ruler, both from 16th-century Iran, featured in Atıl *et al*., *Islamic Metalwork in the FGA*, pp. 195-196 (no. 28). In November, 2004, I saw for the first time two spectacular wrought iron plaques of the same kind (both *ca*. 77 × 27 × 1 cm) apparently from the gates of 14th-century Baghdad (one text is Qurʾānic, the other mentions *Dār al-Salām*). These are now preserved in the Museum of Islamic Art in Doha, Qatar, and are illustrated in *Frankfurt MAK 2004 Exhibition Catalogue*, pp. 146-149.

[7] This is not well documented in the standard literature on Islamic calligraphy. The article EI_2 article "Muʿammāʾ" by C. Edmund Bosworth deals with secret codes, which are called by the same name.

a

Figs. 3.1a-b: The front and back of the astrolabic plate of ʿAlī al-Wadāʿī (#4026). [Courtesy of the The Time Museum, Rockford, Ill.]

b

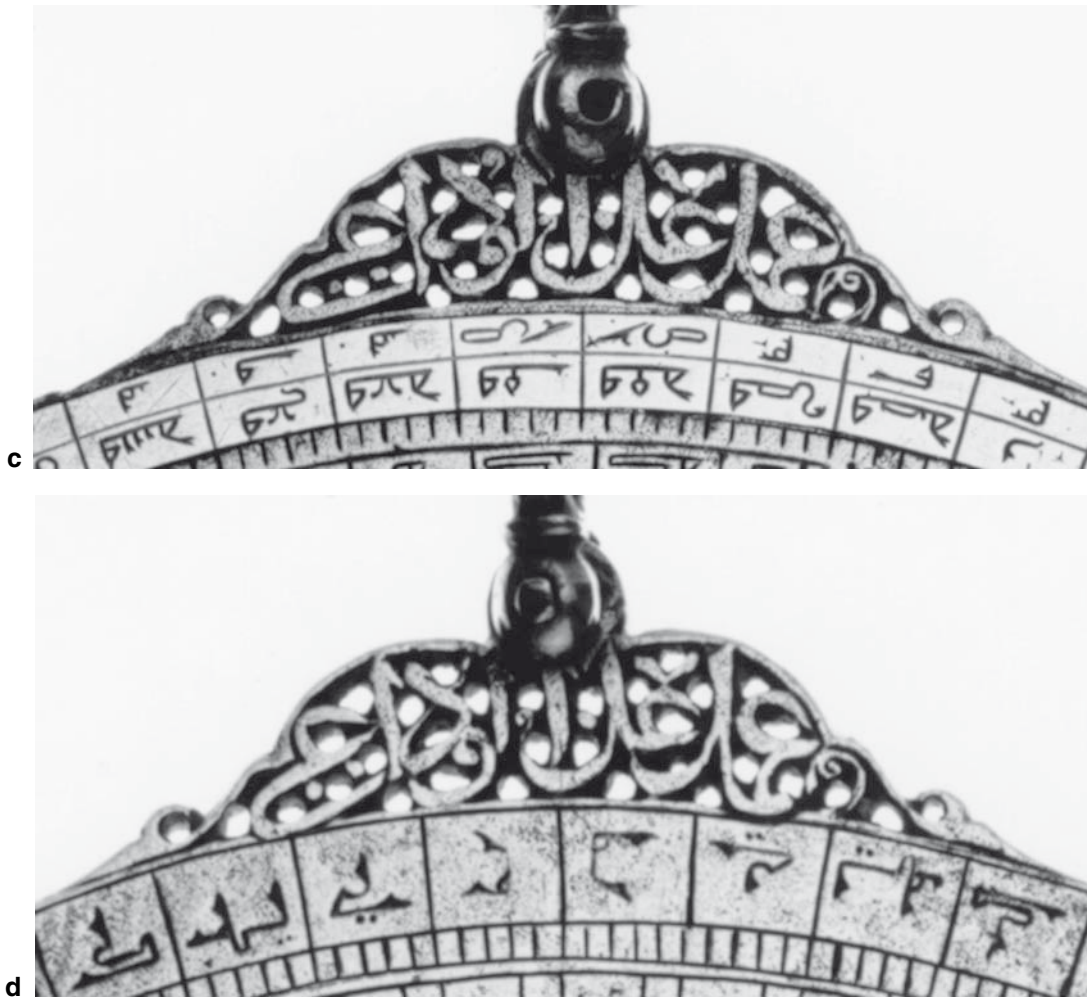



Fig. 3.1c-d: The inscription on the throne, viewed from the front and the back. Is this palindrome unique in Islamic metalwork?

that either he or his ancestors hailed originally from the Yemen.[8] However, this astrolabe is without a doubt of Egyptian or Syrian provenance. The main markings are specifically for the latitudes 30° and 36°, which correspond to Cairo and Aleppo, respectively. This is a rare feature on instruments of this period; indeed; the only other documented instrument serving two specific localities is a 14th-century ivory quadrant preserved in the Benaki Museum in Athens, which bears markings for the two latitudes 30° and 33°, serving Cairo and Damascus (see **Fig. X-1.6**). Syria and Egypt were united under the Ayyubids in the late 12th century: what better way for an astronomer to celebrate the union than to construct an instrument serving a major city in each region? There was a vigorous tradition of astronomy in Syria and Egypt in the 12th century (mainly Syria), 13th century (Egypt), and 14th century (Syria), and al-Wadāʿī's astrolabe is representative of the earlier phase of this tradition.

[8] al-Suyūṭī, *Lubb al-lubāb fī taḥrīr al-ansāb*, 1840 edn., p. 272.

This having been said, and it is more or less what I said already some 20 years ago, I now realize that it cannot be too strongly maintained that 36° was intended for Aleppo, because that latitude was also used for pedagogic purposes as the middle of the 4th climate, indeed, as the middle of the inhabited world. And lest the reader think that this is somewhat strange, we recall that even a century later, Najm al-Dīn al-Miṣrī, based in Cairo, used 36° for all of his calculations, thus rendering his tables only of theoretical interest to his readers (see **Fig. X-1.8**). If Aleppo was not specifically intended, then the piece must have been made in Cairo. (I contemplated removing it from this study, but thought better of that.)

Since the stars move slowly around the ecliptic at a rate of *ca*. 1° per 70 years, the position of the star Regulus, close to the ecliptic, can conveniently be used to date medieval instruments. In this case, the pointer for Regulus on the universal grid (see below) is at ecliptic longitude *ca*. 138 $^{1}/_{2}$°, which correponds to *ca*. 1200. Also, the equinox on the calendar scale (see below) corresponds roughly to Ādhār (= March) 11-12, although at the beginning of the 13th century it actually occurred about midday on March 13. However, a dating to the 13th century is contradicted neither by the nature of the calligraphy nor by what we know about the development of non-standard astrolabes. All that is lacking is an environment for this piece.

One side of the astrolabe—see **Fig. 3.1a**—bears markings of the standard *zarqālliyya* type, representing stereographic projections of the equatorial and ecliptic coordinate systems superimposed one upon the other. The alidade, which would have been fitted with a perpendicular rule that could be moved along the length of the alidade, is now missing. With this at hand, one could convert celestial positions from one coordinate system to the other. Numerous examples of *zarqālliyya* plates survive on astrolabes of varied geographical provenance.

On al-Wadāʿī's *zarqālliyya* the positions of some 19 stars are indicated by inlaid silver studs, but the stars are not named. Presumably, a seasoned medieval astronomer would know which stars the studs were intended to represent. On the rim there are four scales, one in each quadrant, and each running from 0° to 90°. Since these scales start from the top or bottom of the instrument, they would not have been intended for measuring celestial altitudes.

The other side of the instrument—see **Fig. 3.1b**—displays "ogival" altitude markings for latitudes 30° [Cairo] and 36° [Aleppo (?) or the 4th climate (?)]. Such markings were called *maftūḥ* (= "open") in medieval Arabic technical vocabulary, and they are rarely represented on astrolabe plates. The only advantage is that markings for two latitudes can be engraved on one plate. Here markings for each 6° are engraved for latitude 30°, and markings for each 5° for latitude 36°. This accounts for the apparent symmetry of the two sets of markings, which is deceptive.

Now the markings are bounded by the celestial equator, which means that the ecliptic on the rete was similarly limited. This means that we are dealing with an astrolabe of the myrtle type (see further **XIIId**). The myrtle rete illustrated by al-Bīrūnī is shown in **Fig. 3.1e**, and the markings for a single latitude to serve a myrtle rete as illustrated by Najm al-Dīn al-Miṣrī are shown in **Fig. 3.1f**. The advantage of the myrtle rete is that the two halves of the ecliptic are symmetrical. Maybe al-Wadāʿī was unable to resist the temptation to represent both halves of the ecliptic on a single arc (see **9**).

A disadvantage of the "open" altitude markings is that one has to be a fairly competent

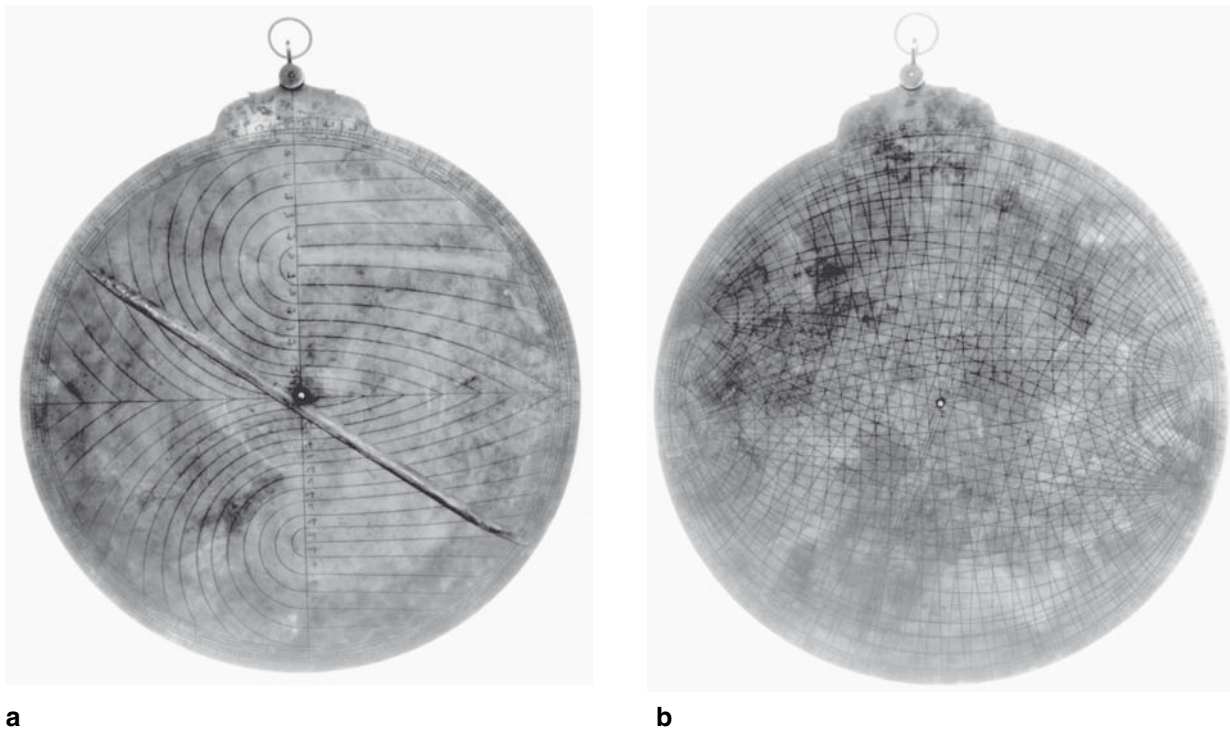
astronomer in order to use them. The basic function of the astrolabe, which is to display the instantaneous configuration of the heavens relative to the local horizon, is lost: with these markings we have progressed to a mathematical abstraction. Also, the markings for each latitude are discontinuous at the meridian: some caution is necessary in using them for operations that involve moving from one quadrant to the other. The amount of rotation of the rete from one position to another, which is a measure of the passage of time, must take into consideration these discontinuities. Of course, this side of the instrument can only be used with a rete, now missing. Probably the original rete was a regular astrolabic rete; a more sophisticated rete would not achieve any purpose. Another apparent disadvantage is that no azimuth circles are shown, but the medieval astronomers knew enough about the mathematical equivalence of the two problems of determining the hour-angle and the azimuth from an observed celestial altitude at a specific latitude that they could determine azimuths using altitude curves.

Around the circumference are various scales. The second of these (counting from the rim) runs clockwise from 0° to 360° starting at the bottom. The first (upper half) has two scales from 0° to 90° starting at the sides. These scales are, for some reason, inlaid in silver. The first (lower right) bears a scale from 0° to 90° starting at the side: this was probably intended for measuring celestial altitudes. Thus there would have been an alidade on top of the rete, indeed a curious arrangement. (As we have observed, the scales on the front of the instrument are inappropriate for measuring altitudes, even though there was an alidade on that side.) The first (lower left scale) is for measuring the shadow length with standard medieval base twelve for an altitude displayed on the opposite quadrant. The three inner scales are for finding the solar longitude corresponding to any date in the Syrian calendar or the (Egyptian) Coptic calendar. Since both calendars are represented, and both [Aleppo (?)] and [Cairo] are served by the instrument, it is still impossible to decide conclusively whether the astrolabe was constructed in Egypt or Syria.

Two small holes have been deliberately and carefully drilled through the instrument on the lower half of the outer scale at 30° below the east-west line: what function these could have performed is not clear, though see below.

In brief, the instrument is much more interesting than most medieval astrolabes, in that it could only have been used by a very competent astronomer. Yet the *zarqālliyya* plate achieves only one coordinate transformation; a single *shakkāziyya* plate with a special alidade or a double *shakkāziyya* grid, on the other hand, achieves any coordinate transformation. The plate for two latitudes works precisely for these. Yet there are four quadrants on each side of a plate: why not have markings for four latitudes? To serve as a "universal" Ayyubid instrument, markings for Damascus and, say, Jerusalem, would also be useful: see now **7*** below. Maybe there was originally another plate that fitted on top of this one, *secured in position by means of the two small holes on the rim*.

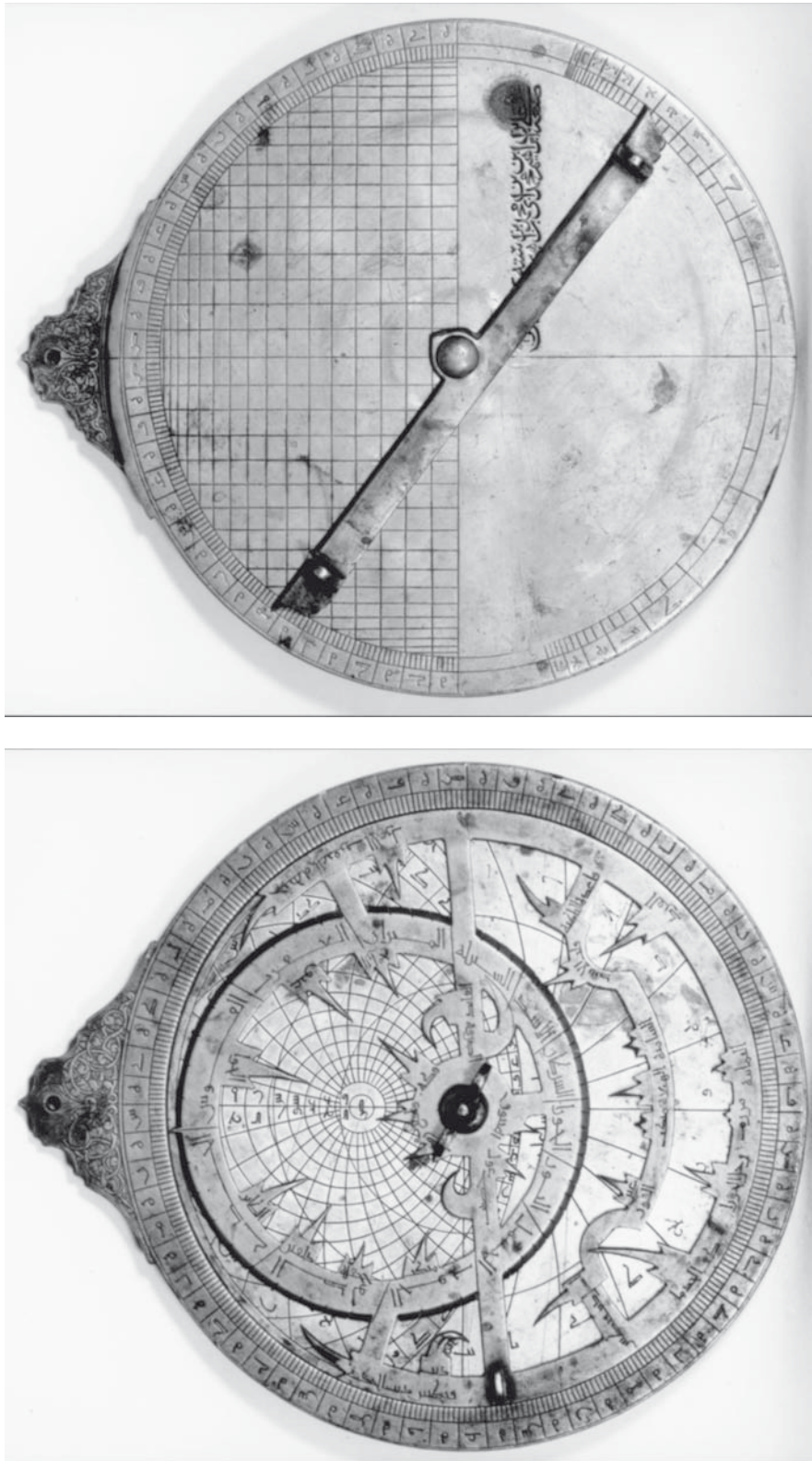
Finally, we draw attention to one aspect of the splendid universal astrolabe made by the Aleppo astronomer Ibn al-Sarrāj in 729 H [= 1328/29] (#140), which survives in the Benaki Museum in Athens. This instrument can be used universally in five different ways (see **5.1**). When he had devised all of these various parts for his instrument, Ibn al-Sarrāj found that he had one side of one plate left over: this he used for "open" altitude markings for latitudes 30° (Cairo) and 33° (Damascus), even though he himself lived in Aleppo. Thus Ibn al-Sarrāj's

a b

Figs. 3.2a-b: The front and back of the copy (#4027). [Courtesy of Christie's of London.]

astrolabe performs each of the functions of that of his predecessor al-Wadāʿī and more, more, in fact, than any other astrolabe ever made in either the Near East or Europe.

3.2 A later copy

International Instrument Checklist #4027.
London, Ahuan Gallery, acquired 1990.
Brass, diameter 38.7 cm, thickness 1 mm.
Bibliography: Described by D. A. King in *Christie's London 27.9.1990 Catalogue*, p. 39 and insert (lot 189).

One of the many questions surrounding al-Wadāʿī's instrument is how it came to pass that someone two or three centuries ago made a faithful copy of it more than twice as large as the original. The maker was perhaps working in India, where it became a tradition to make very large instruments. The palindrome inscription is gone, and the latitudes 30° and 36° are not identified on the copy. The maker was a competent astrolabist but did not have the initiative to construct either a new rete or a new alidade with movable cursor for his copy. The engraving is in an elegant *kūfī* script, with a distinctive *lām-alif* ligature resembling a pair of crossed swords, but this is not necessarily mean that the instrument is early. The use of *ṣād* for *sīn* (= 60) indicates Western Islamic influence, which complicates the matter still further. Again, an environment is lacking, and, this time, a motive as well. Both instruments are now with the same owner in London.

Figs. 4a-b: The front and back of the astrolabe of the young Ibn al-Shāṭir (#6). [Courtesy of the Observatoire de Paris.]

4 A standard astrolabe by Ibn al-Shāṭir, dated 1325/26

International Instrument Checklist #6.
Paris, Observatoire de Paris. Donated by Count Pertuis of Beirut.
Brass. Diameter: 162 mm. Thickness: 8 mm.
Bibliography: See Gunther, *Astrolabes*, I, p. 121 (no. 6), with a copy of the inscription; and Mayer, *Islamic Astrolabists*, p. 42 (lists the maker separately from Ibn al-Shāṭir). The first description is in *Paris IMA 1993-94 Exhibition Catalogue*, p. 435 (no. 331). Various popular works have featured illustrations.

This astrolabe is a splendid example of a Mamluk astrolabe of the standard variety. It is signed by ʿAlī ibn Ibrāhīm ibn Muḥammad ibn Abī Muḥammad ibn Ibrāhīm, who is without doubt to be associated with Ibn al-Shāṭir, if as a young man, even though the elegant *thulth* calligraphy of the inscription is different from that on his other instruments.

The front and back of the throne are decorated with an intricate foliated design, and the suspensory apparatus is missing. The scale of the rim is divided and labelled for each 5° and subdivided for each 1°. The mater itself is lightly engraved close to the rim with a double circle, which has no astronomical significance, and there is a peg at the bottom to hold the plates.

The rete is in the late Abbasid tradition. The equinoctial bar is rectilinear and there is a short solstitial bar of the same width between the central disc and the northern ecliptic. There is a handle at the left-hand end of the former bar. The equatorial bar is interrupted near its ends by two roughly semi-circular arcs (open downwards) that accommodate two long pointers attached to the circumferential frame. The one for (*al-*)*kaff al-jadhmāʾ* on the left is so long that its tip ends on the frame anyway, and likewise the pointer for *al-ṣarfa* is engraved over the ecliptic frame at the end of Leo and Virgo. Each sign of the ecliptic is divided into 6°-intervals, and the names of the signs are standard. The star-pointers are dagger-shaped, most straight, a few curved, and a few even talon-shaped. The 31 stars represented are:

aṣl dhanab qayṭus
kaff al-jadhmāʾ
ghūl
ʿayn al-thawr
al-ʿayyūq
rijl al-jawzāʾ
mankib
mirzam

---

al-hanʿa (lunar mansion)

---

al-yamāniya
al-shaʾāmiya
al-fard
qalb al-asad

al-aʿzal
al-qāʾid
al-rāmiḥ
fakka
ʿunuq
jabhat al-ʿaqrab
al-ḥawwāʾ

---

wāqiʿ
al-ṭāʾir
dulfīn
ridf
jaḥfala
dhanab al-jady
mankib

qāʿidat al-bāṭiya	*khaḍīb*
al-ṣarfa	*dhanab qayṭus*

The four plates bear altitude circles for each 6° and azimuth circles above or below the horizon for each 10° (indicated by + or - below). The arguments for both sets of curves are labelled on both sides; for azimuth curves above the horizon the arguments are just above the horizon continuing around the circumference to the meridian, and for those below it, they are just below the horizon and below the central "crescent". Also, the seasonal hours are numbered in *abjad* notation. The words *al-maghrib* and *al-mashriq* are engraved at the ends of the horizon. The following latitudes are served, the lengths of longest daylight being also given:

1a	+	21°	13;17^h	[0]
1b	-	24	13;30	[0]
2a	-	29;56	13;56	[0]
3a	-	32	14; 7	[0]
2b	+	33;30	14;14	[0]
3b	-	35	14;22	[0]
4a	+	36;30	14;31	[0]
4b	+	66;25	24^h	[0]

Ibn al-Shāṭir has here used the obliquity of the ecliptic 23;35° accepted by Ibn Yūnus and al-Marrākushī (note that his values for the lengths of daylight are all accurately computed for this parameter); his own derivation of the more accurate value 23;31° took place later.

The specific latitudes are clearly intended to serve Mecca, Medina, Cairo, Jerusalem, Damascus, ?? (Hims, Hama or Tartus), and Aleppo, the major localities in the Mamluk world. Significant is the latitude 29;56° used for Cairo: al-Marrākushī had used 29;55° in his compendium, whereas Ibn Yūnus three centuries previously had measured more accurately 30;0°. The value 29;56° must have been recently measured and soon thereafter rejected; it is not recorded in any other known source.

The back bears two altitude scales divided for each 5°, subdivided for each 1° and labelled for each 5°. Inside these is a double sine quadrant with parallel horizontals and verticals for each 5° up to 80°. Below the horizontal diameter on the rim there are unmarked horizontal shadow scales to base 7 (left) and 12 (right), divided and labelled for each 3 up to 21 and 33, respectively, and subdivided for each 1 unit. The remaining space below the horizontal diameter is devoid of markings but for the inscription in the upper part of the right-hand quadrant:

صنعه علي بن إبراهيم بن محمد بن أبي محمد بن إبراهيم سنة ستة وعشرين وسبعميّة (!)

"Constructed by ʿAlī ibn Ibrāhīm ibn Muḥammad ibn Abī Muḥammad ibn Ibrāhīm in the year 726 [= 1325/26]."

Note the incorrect *shadda* on the *yāʾ* in *sabʿimiʾa*. Ibn al-Shāṭir's great-grandfather is more often referred to as Humām, and from this inscription we learn that his name was Abū Muḥammad Humām.

The alidade is rectilinear and without markings. The vanes are unusual in that they have a circular protrusion on the top with a third hole. The pin has a thread that fits into a wing-nut.

5 Two instruments by Ibn al-Sarrāj of Aleppo

5.1 A quintuply-universal astrolabe dated 1328/29

International Instrument Checklist #140.
Athens, Benaki Museum, inv. no. 13178 (formerly A.α.28). Owned by a series of Egyptian astronomers from the 15th to the 19th century (see below). Purchased by the Greek art-collector and benefactor Antonis Benaki (b. Alexandria, 1873, d. Athens, 1859) from Ali Bey in Baghdad in 1921.
Brass. Diameter: 158 mms. Thickness: 6 mms.
Bibliography: Gunther, *Astrolabes*, pp. 285-286 (no. 140: "If this instrument ... be all of one period, it is an important and early example"), and fig. 133 on p. 286 (front only); King, "Astronomy of the Mamluks", p. 544-545; *idem*, "Strumentazione", pp. 165, 171, and 175; and *idem*, "The Astronomical Instruments of Ibn al-Sarrāj", in *Studies*, B-IX, for a summary). The first published description is in *Paris IMA 1993-94 Exhibition Catalogue*, pp. 434-435 (no. 330). On the star-positions see Stautz, *Mathematisch-astronomische Darstellungen auf mittelalterlichen Instrumenten*, pp. 66 and 69 (SA8) and fig. 3.6g on p. 213. The instrument and its mode of operation is described in greater detail in Charette & King, *The Universal Astrolabe of Ibn al-Sarrāj*, forthcoming.

This is without doubt the most sophisticated astronomical instrument surviving from the Middle Ages and probably the most sophisticated ever made between Antiquity and 1600. It is carefully and beautifully engraved, with the inscriptions written in unpointed *kūfī*. Not only is the instrument complete, but additional inscriptions attest to its fate in the Middle Ages. It was still in Egypt in the 19th century but somehow it ended up in Baghdad, where Benaki acquired it in 1921. Also, we are fortunate in possessing a set of instructions on the use of all of its component parts. In view of the fact that François Charette and I have an detailed study of this instrument as well as its *modus operandi*, based on all the available texts, I shall refrain here from a full description. It is, however, worth pointing out that Ibn al-Sarrāj wrote a treatise on a simpler version of the universal astrolabe, with a calendrical scale around the front rim: this is the instrument later "reinvented" by John Blagrave (Reading, 1585): see **Fig. X-5.2.5**.

In short, one can use the half of the rete that resembles one-half of a standard rete firstly with the universal *shakkāziyya* plate, secondly with the plate of horizons, and thirdly with a series of quarter-plates serving all latitudes. Then one can use the *shakkāziyya* part of the rete with the universal *shakkāziyya* plate, and finally one can use the trigonometric grid on the back to solve any of the standard problems of spherical astronomy for any latitude. These, then, are the five different ways in which the instrument can be used universally.

The throne is composed of interwoven fronds, elegantly worked. It is similar to, but less complex than that of al-Nīsābūrī (**2** above), although it is now pierced like that of al-Wadāʿī (**3** above).

The rete is composed of two sets of markings. The upper half is a semicircular *shakkāziyya* grid with declination and meridian circles drawn for each 6° of argument. The horizontal diameter is marked for each 6° of azimuth. The lower half of the rete displays the ecliptic and

Fig. 5.1a: The front of the astrolabe of Ibn al-Sarrāj (#140). [All photos courtesy of the Benaki Museum, Athens.]

Fig. 5.1b: The back, showing the remarkable trigonometric grid and an ingenious solar calendrical scale. There is a problem here: the equinox is at Ādhār 10, which corresponds to the 17th century! I would have expected Ādhār 12.5 (see Turner, "Dating Astrolabes", p. 550). We note that the solar table of al-Tīzīnī (Damascus, mid 15th century) has a solar longitude of 0;3° for Ādhār 11, presumably for midday at Damascus (MS Paris B.N. ar. 2558, fol. 8v). This feature of Ibn al-Sarrāj's scale demands further investigation; I have not observed any problems of this kind with other Mamluk scales.

c

d

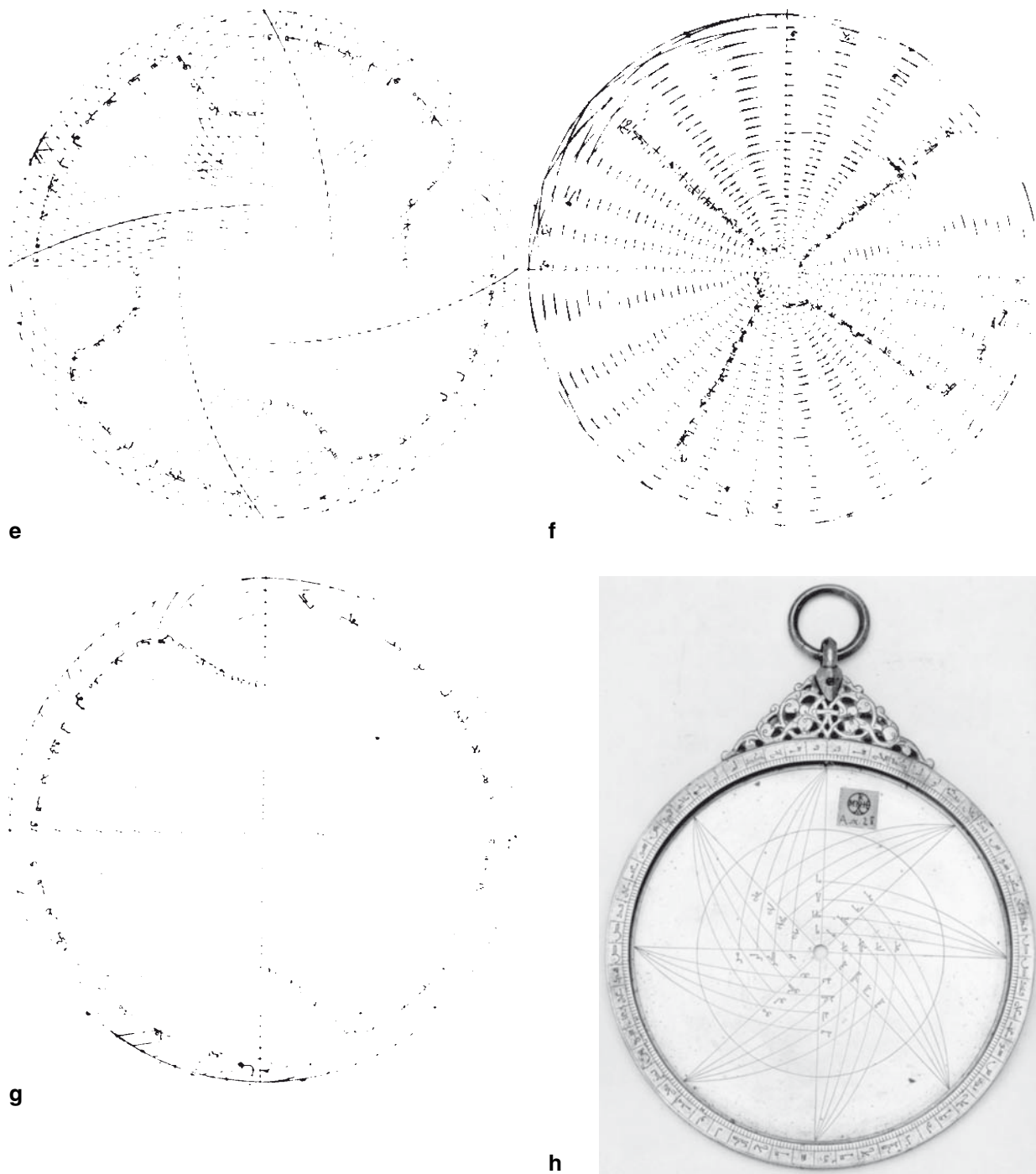
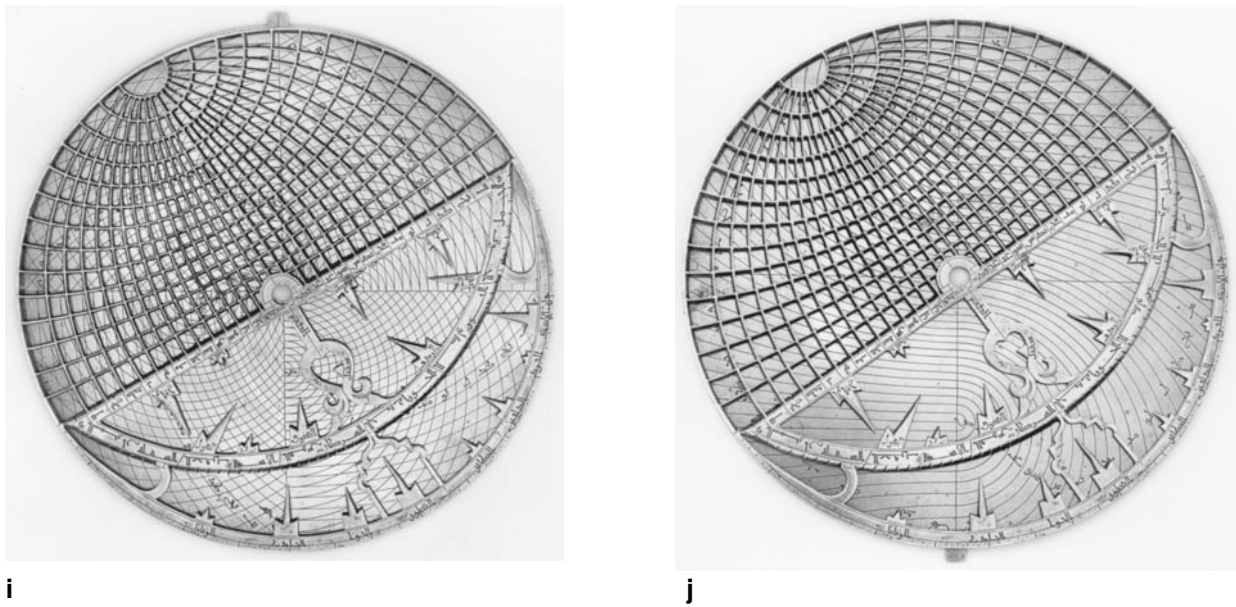
Figs. 5.1c-d: Details of the rete.

star-pointers. The two halves of the ecliptic north and south of the celestial equator have been superposed one upon the other, as have the two halves of the star chart representing the stars north and south of the celestial equator. Some 19 stars are displayed on the rete:

al-qāʾid *al-ḥādī* *suhayl* *al-fard*
al-rāmiḥ *al-ʿayyūq* *al-ṭāʾir* *qalb al-asad*
al-ghūl *al-dubb* *al-dulfīn* *fam al-ḥūt*
al-zubānā *al-ḥawwāʾ* *al-ridf* *al-mankib*
fakka *al-ʿabūr* *rukba*

The positions of the stars are accurate for the epoch of the instrument (Stautz).

The five plates constitute a remarkable testimony to the ingenuity of Ibn al-Sarrāj. Eight sides each display four quadrants of astrolabic markings for four different latitudes, and together serving each 3° of latitude from 3° to 90°, as well as 31°, 33;30°, and 36;30° (for Alexandria, Damascus, and Aleppo): see **Fig. 5.1e**. Since the markings of one-half of an astrolabe plate do not fit exactly in a quadrant, the excess markings have been folded over so as indeed to fit in a quadrant. Another side bears a complete set of *shakkāziyya* markings on one side. Yet another—see **Fig. 5.1f**—bears two half sets of altitude circles above and below the horizon for latitudes 30° and 33° (see **3.1**). The mater bears eight sets of four half-horizons symmetrically arranged, each set inclined at 45° to the next. The latitudes for each arc are labelled, and the eight sets serve latitudes between 11° and 48°: see **Fig. 5.1g**.

The back bears the usual altitude scales with which, using the alidade fitted with sights, one can measure the altitude of the sun or stars. The grid on the upper half of the back of Ibn al-Sarrāj's astrolabe is of a kind unattested on any other medieval scientific instrument. It consists of the declination circles of two orthogonal sets of *shakkāziyya* markings, drawn for each 5°

Figs. 5.1e-g (e) One of the plates, serving latitudes 27°, 30°, 33° and 36°.
(f) Another serving latitudes 75°, 78°, 81° and 84°. There are six other sets of such markings.
(g) The side with "open" markings for latitudes 30° (left) and 33° (right). Each set is one-half of a complete set of altitude circles for a full myrtle plate (compare **Fig. 3a**). Note that the altitude circle for 30° below the horizon at latitude 30° is a straight line.
(h) The markings for the horizons on the mater.

Figs. 5.1i-j: (i) The rete over one of the plates with *musattar* markings for four different latitudes. (j) The rete over the plate with the two sets of half-markings for latitudes 30° and 33°.

of arguments, and is to be used in conjunction with the larger of the two alidades. The lower half of the back of the astrolabe bears semicircular scales for finding the solar longitude from the date in the Syrian calendar. The vernal equinox corresponds to the end of Ādhār 10 (see the caption to **Fig. 5.1b**). Inside these scales on Ibn al-Sarrāj's astrolabe are two shadow squares, the one on the right for base (*i.e.* gnomon length) 12 and the one on the left for base 7.

The inscription below the centre of the back reads:

عمل أحمد بن السراج لمحمد بن محمد التنوخي | في سنة ذكط

"Made by (ʿ*amal*) Aḥmad ibn al-Sarrāj for Muḥammad ibn Muḥammad al-Tanūkhī in the year 729 (Hijra) [= 1328/29]."

al-Tanūkhī has not yet been identified.

The alidade bears two different non-linear scales for use with the trigonometric grid on the back of the astrolabe. The radial rule bears a non-linear scale for measuring the declination of the stars and ecliptic positions on the rete and to serve as a variable horizon on the *shakkāziyya* plate. It bears additions by al-Wafāʾī, who mentions these in his treatise.

To use this astrolabe one has to be completely in control of the underlying principles, and keep ones wits about one to make sure one is using the appropriate quadrant or semicircle of latitude-dependent markings. **Figs. 5.1i-j** show the instrument ready to use in two of the possible combinations. As I see this volume through second proof (December, 2004), François Charette is completing the commentary to our forthcoming joint publication on this splendid piece.

Later additions: There are four notices of possession engraved around the rim, the first inlaid in silver although much of the silver is gone now. The inscriptions read:

(1) “Property (*milk*) of Aḥmad al-Rīshī (in the) year 830 (H) [= 1426/27]”—Aḥmad al-Kawm al-Rīshī was one of the leading astronomers in Cairo in the late 15th century: he prepared a recension for Cairo of the astronomical handbook (*zīj*) of Ibn al-Shāṭir.[9]

(2) “Owned by (*malakahu*) ʿAbd al-ʿAzīz al-Wafāʾī al-Mīqātī in the year 854 (H) [= 1450/51]”—al-Wafāʾī (died *ca*. 875 H [= 1475]) was one of the leading astronomers of Cairo in his time, and his interest was mainly in astronomical instruments. It was he who wrote the treatise on the use of this instrument, complaining that Ibn al-Sarrāj had not done so. It is much to al-Wafāʾī’s credit that he could understand every part of this instrument.[10]

(3) “Owned by Muḥammad ibn Abi ‘l-Fatḥ al-Ṣūfī (in the) year 885 (H) [= 1480/81]”—al-Ṣūfī (died *ca.* 910 Hijra [= 1510]) was another leading astronomer of medieval Cairo, responsible for a recension for Cairo of the astronomical handbook of Ulugh Beg of Samarqand, and also for a number of treatises on instruments.[11]

(4) “Owned by ʿAlī Abū Bakr al-Khashshāb (in the) year 1273 (H) [=1856/57]—ʿAlī al-Khashshāb was muwaqqit at the Jāmiʿ al-Baḥr in Damietta, author of some astronomical works and former owner of several of the scientific manuscripts now in the Egyptian National Library.[12]

5.2 An unsigned mater from a standard astrolabe

International Instrument Checklist #4037.
London, Nasser D. Khalili Collection, inv. no. 3. Acquired from Alain Brieux in Paris in 1982. Earlier provenance?
Brass. Diameter: 158 mm.
Bibliography: *London Khalili Collection Catalogue*, I, p. 218 (no. 125), with colour photos of the front and back: “probably Iran, 14th century”.

This mater is adorned with the same elegant *kūfī* script as the Benaki astrolabe, and I suspect that it is also due to Ibn al-Sarrāj. One may, for example, compare the disinctive forms of the *ʿayn* for 70 on the front of the mater with that on the back of the Benaki piece.

Each side of the throne has two circular lobes flanked by an extended one and a ripple on the outside. There are two circular holes. The suspensory apparatus appears to be original. The scale of the rim is marked without hundreds or tens.

Inside the mater is a plate of eight sets of half-horizons (unusual) for latitudes:

13°	23	33	43	53
14	24	...	...	54
....				
19	29			59
20	30	40	50	60

[9] Suter, *MAA*, no. 428, and *Cairo ENL Survey*, no. C41.
[10] Suter, *MAA*, no. 437, and *Cairo ENL Survey*, no. C61.
[11] Suter, *MAA*, nos. 447/460 (confused), and *Cairo ENL Survey*, no. C98.
[12] *Cairo ENL Survey*, no. D120, and *Cairo ENL Catalogue*, I, p. 750.

a

b

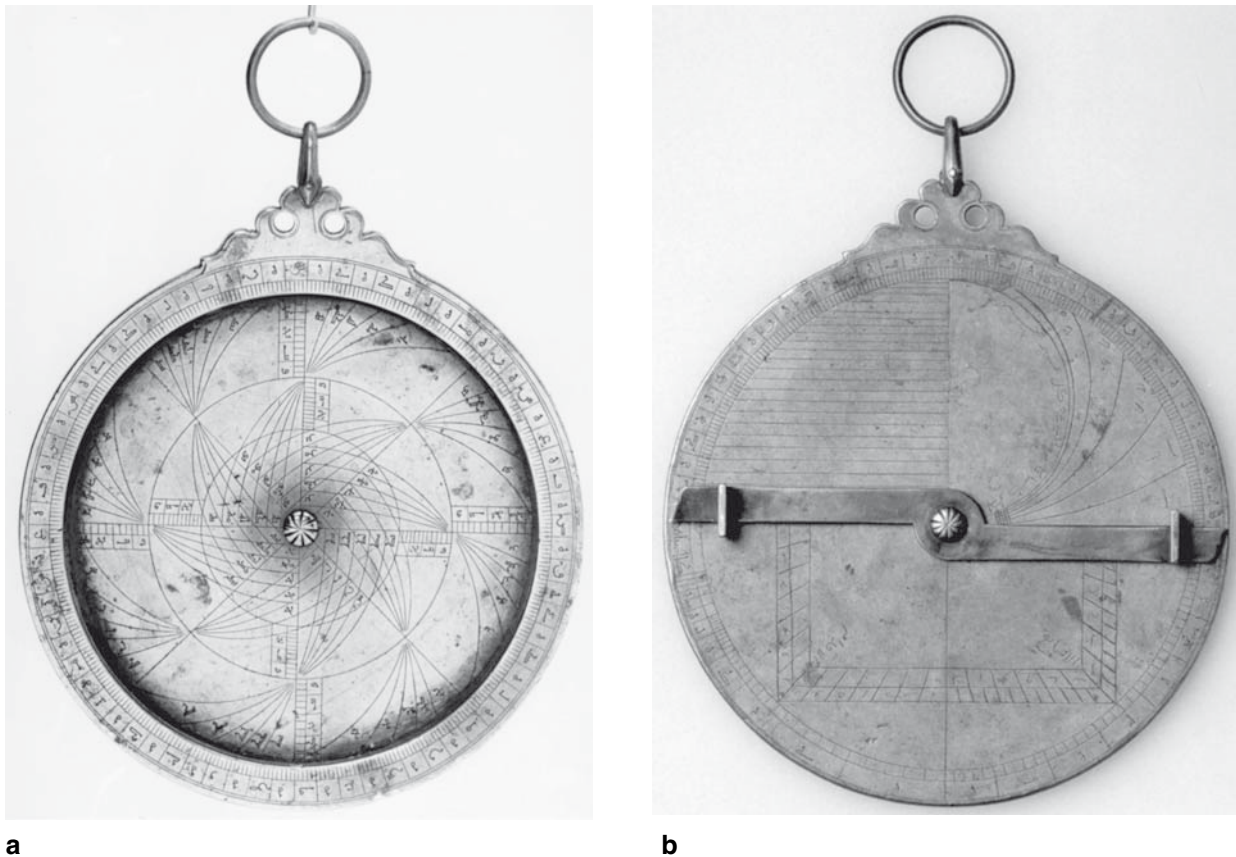



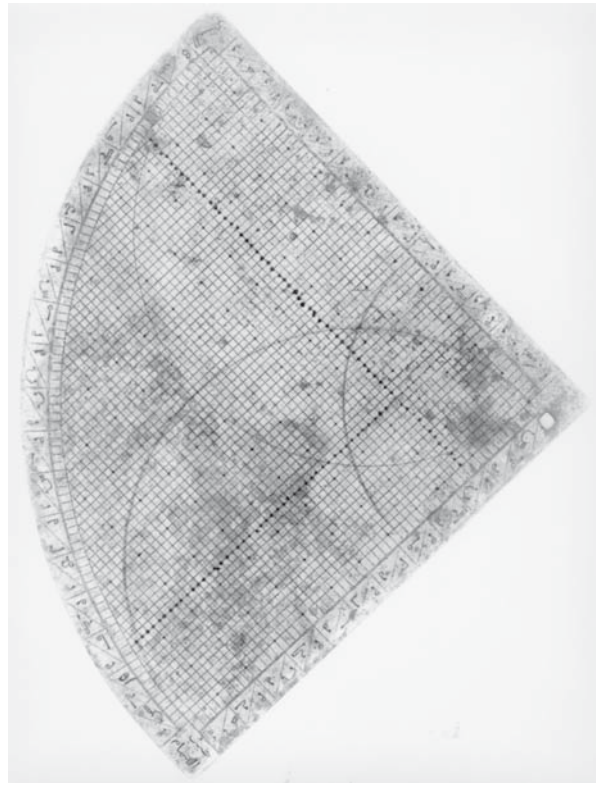
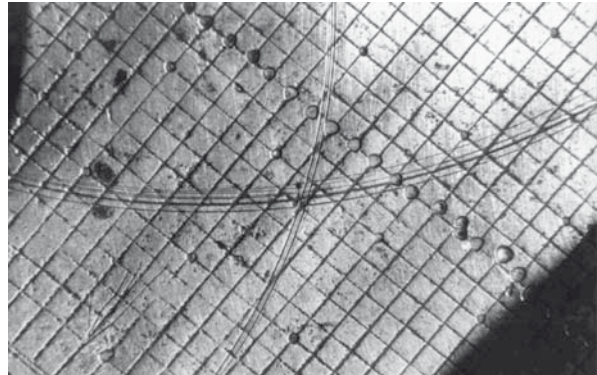
Fig. 5.2a-b: The front and back of the unsigned mater (#4037). Note the throne, which is typical of Iranian astrolabes (compare **Figs. XIIIa-6.1** and **6.2**). If the piece is by Ibn al-Sarrāj, one may wonder what he was doing making standard astrolabes, and if it was just to make an honest living, why he never finished the markings on the back. [Photos from the archive of the late Alain Brieux, courtesy of Dominique Brieux.]

From the omissions in this matrix it is perhaps possible to deduce that there were originally plates for latitudes:

21;30° (21°/22°) 31° 32° 41;30° (41°/42°),

which would ensure that Mecca, Alexandria, Jerusalem and Constantinople were represented, as well as 36° for Aleppo and 33° or 33;30° for Damascus. On each axis there is a declination scale marked 6°-12°-18°-23;35° on both sides of the equinoctial circle.

The back bears two altitude scales divided 5°/1°-5°. In the upper left quadrant there is a sine quadrant with horizontal parallels for each 3° up to 60° and then each 5° up to 80°. On the rim of the lower left quadrant there is a shadow-scale to base 12 labelled *ẓill aṣābi*ʿ and opposite this is an unmarked scale which serves to find the [solar altitude at the beginning of the ʿ*aṣr* prayer] as a function of the meridian altitude, which one must feed in on the scale of the upper left quadrant. The remaining markings are later—see below.

The alidade is counter-changed at the middle and not marked. The pin has a button divided into ten sectors.

Figs. 6.1a-b: The front and back of the quadrant of al-Mizzī (#5005). [Courtesy of the Davids Samling, Copenhagen.]

Figs. 6.1c-d: Details of al-Mizzī's quadrant (#5005). [Photos by the author, courtesy of the Davids Samling.]
(c) Part of the horizon and two star-positions.
(d) Detailed investigation should be undertaken to see whether the axial semicircles and declination quadrant are original. Certainly, this does not look like the work of the master.

Later markings: In the upper right quadrant of the back there is a universal horary quadrant, and below the horizontal diameter there is a double shadow box (base 7 and 12). All of these markings and the unhappy inscription in Ottoman *naskhī* script on the horary quadrant —*ḥudūd sāʿāt zamāniyya fī kull ʿarḍ ṣ*, that is, the limits of the seasonal hours for all latitudes (up to) 90°"—postdate the mater by several centuries.

6 Two instruments by Muḥammad ibn Aḥmad al-Mizzī

6.1 An astrolabic quadrant dated 1329/30

International Instrument Checklist #5005.
Copenhagen, Davids Samling, inv. no. 16/1988. Purchased in Damascus *ca*. 1850 by the grandfather of Ruth Paulding of California, later given to Ruth Paulding and by her to her cousin, Professor John Carswell, in 1973. Auctioned at Sotheby's of London on 13.4.1988.
Brass. Radius: 155 mms.
Bibliography: Mayer, *Islamic Astrolabists*, pp. 61-62, mentions four quadrants by al-Mizzī but not this one. See Fehérvári, "Quadrant of al-Mizzī" for a detailed non-technical description of this piece, as well as *London Sotheby's 13.04.1988 Catalogue*, p. 122 (lot no. 267) with illustrations of the front and back, and *Copenhagen DS Catalogue*, pl. 362 on p. 214 (colour illustration of front). A new description is in *Paris IMA 1993-94 Exhibition Catalogue*, p. 438 (no. 333). See also Morley, "Arabic Quadrant", for another instrument by al-Mizzī.

The front bears an inscription outside the outer scale:

صنعه محمد بن أحمد المزّي لسليمن بن محمد بن سليمن بدمشق | سنة ذل

"Constructed by Muḥammad ibn Aḥmad al-Mizzī for Sulaymān ibn Muḥammad ibn Sulaymān in Damascus in the year 730 (H) [= 1329/30]."

There are two sights at either end of the meridian. The horizon is marked "the horizon for latitude 33;30°". There are altitude circles for each 3° that are continued inside the circle for the summer solstice, and within that circle even below the horizon (for what purpose it is not clear). The southern ecliptic is divided for each 3° by dots; there are no divisions on the northern ecliptic. There is a curve for the *ʿaṣr*, so marked, and two unmarked curves, the lower one concave upwards spanning the two outer circles, and the upper one convex upwards incorrectly spanning points on each branch of the ecliptic. These appear to serve the determination of the duration of morning and evening twilight, the lower one to be measured from the bottom (0°) of the outer scale and the upper one to be measured from the other end of the outer scale. The names of 13 stars and their right ascensions (normed, that is, measured from Capricorn 0°) are written below the horizon and also along the meridian:

al-ʿayyūq	*al-fard*
awwal al-minṭaqa	*qalb al-asad*

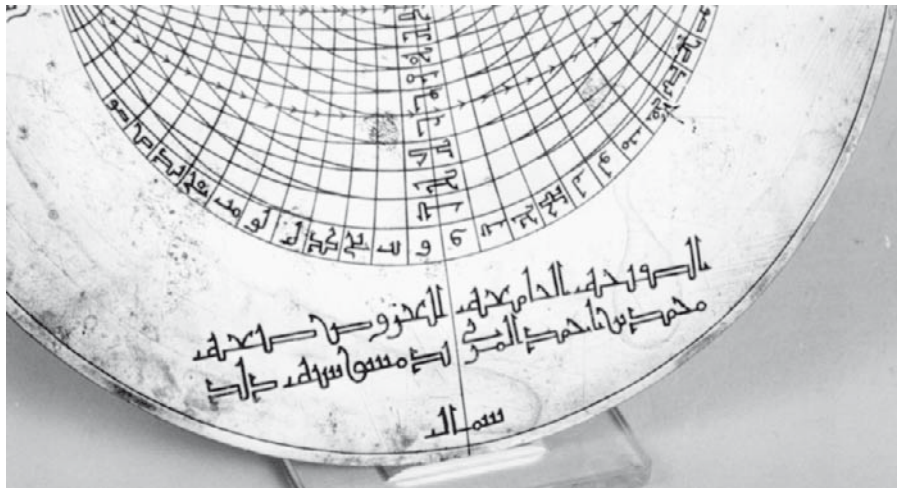



Fig. 6.2a: This universal plate in a Maghribi astrolabe (#1204) constructed by al-Ḥusayn ibn ʿAlī in Tunis in 709 H [= 1309/10], was made separately by al-Mizzī in 734 H [= 1333/34]. It is unclear how the plate came to be part of the astrolabe. [Photo by the author, courtesy of the Whipple Museum for History of Science, Cambridge.]

rijl al-jawzāʾ
yad al-jawzāʾ
al-yamāniya
al-ghumayṣāʾ
ṣadr al-dubb
janāḥ al-ghurāb
al-aʿzal
al-j-w-b-ʾ (?)
al-ṭāʾir

The main markings on the back are a set of horizontal and vertical parallels for each unit. The intersections of each fifth are dotted, as are the lines for 12 units, which serve to find the solar altitude at the *ʿaṣr*. There are two axial semi-circles for finding sines and cosines and an unlabelled double (carelessly-drawn) quarter-circle with radius 24 units for finding the declination.

6.2 An Ibn Bāṣo-type plate dated 1333/34

International Instrument Checklist #1204.
Cambridge, Whipple Museum of the History of Science: inv. no. 1759. Earlier provenance?
Brass. Diameter: 144 mm (mater).
Bibliography: The plate is not mentioned in Mayer, *Islamic Astrolabists*, pp. 61-62. See now Calvo, "Ibn Bāṣo's Universal Plate", pp. 763-764.

The Cambridge instrument of the Maghribi astrolabist al-Ḥusayn ibn ʿAlī contains a spurious plate signed by al-Mizzī. Either this astrolabe, made in Tunis in 709 H [= 1309/10], actually came into the hands of al-Mizzī, and he made the plate especially for it—which is unlikely—or the plate was taken from one of his own astrolabes. In any case the plate raises interesting

questions about the transmission of the "Western" "Ibn Bāṣo-type plate to the Mamluk world.[13] The *kūfī* inscriptions on the plate strongly resemble those on the plates of al-Ḥusayn ibn ʿAlī.

On one side there are altitude circles for each 6° and azimuth curves for each 10° "for all localities with latitude 13°". This unusual choice of latitude argues against al-Mizzī having made the plate especially for this latitude. The meridian, the altitude circle at altitude 18° and that for 60°, as well as the prime vertical, are all in fish-bone. The hours are written in words.

On the other side there is an Ibn Bāṣo-type projection with the inscription:

الصفيحة الجامعة للعروض صنعة | محمد بن أحمد المزي بدمشق سنة ذلد

"The universal plate for all latitudes (*al-ṣafīhā al-jāmiʿa li-ʾl-ʿurūḍ*) constructed by Muḥammad ibn Aḥmad al-Mizzī in Damascus in the year 734 (Hijra) [= 1333/34]."

7 An unsigned undated Mamluk astrolabe copied from one by al-Mizzī

International Instrument Checklist #4164.
Cairo, Museum of Islamic Art: 15368. Formerly in the Harari Collection (no. 401). Earlier provenance?
Brass. Diameter: 162 mm. Thickness: 4 mm.
Bibliography: None.

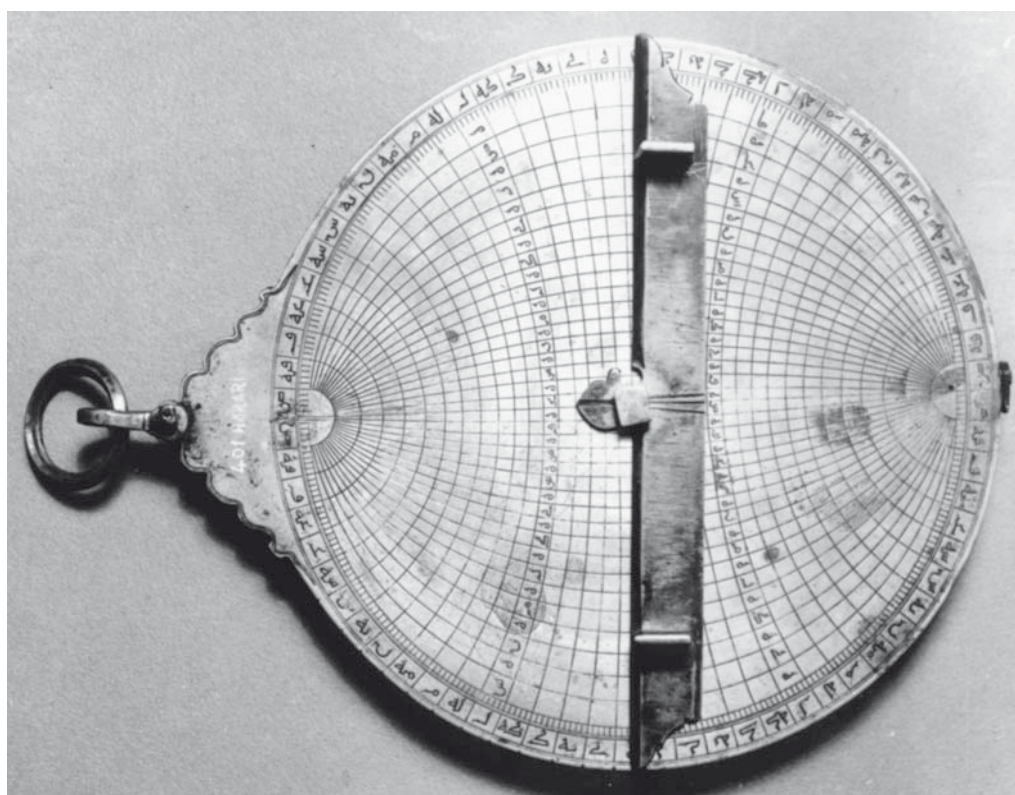
The use of al-Mizzī's distinctive parameters of 33;27° for the latitude of Damascus and 23;33° for the obliquity of the ecliptic (see **I-2.1.3** and **II-9.2**) is a sure indication that this instrument is to be associated with al-Mizzī. However, there are some problems of orthography and astronomical parameters, and these I take to be an indication that the instrument was *copied* from one by him. The instrument is important in that it shows clearly the kind of astrolabe for which al-Mizzī was famous.

The throne is basically triangular with a small prominent protrusion followed by three ripples on either side of a circular protrusion at the centre. There is a snake-like double line around the rim of both the front and back of the throne. The simple head-set-type shackle bears a circular ring with diamond-shape cross-section. The mater and rim are of one piece. The scale of the rim is divided 5°/1°-5° (without hundreds). The hole inside the rim of the mater is about 2.5° to the left of the bottom of the rim. See below on a curious appendage.

The rete is unusual, and distinctive in design. The equinoctial bar extends only inside the ecliptic and has semicircular frames (open downwards) at both ends. The solstitial bar extends also only within the ecliptic, the part above the central disc consisting mainly of two circular frames (the upper one actually slightly pear-shaped). The circumferential frame has two semicircular insets at the middle of each of the lower quadrants. A roughly V-shaped frame consisting of two fronds of circular arcs joins the equinoxes to the circumferential frame; an additional arc on either side joins the upper parts of the fronds to the circumferential frame again. The various frames have been skilfully designed to bear the star-pointers in an optimal

[13] This is discussed in Calvo, "Ibn Bāṣo's Universal Plate in the Maghrib and East".

a

b

Figs. 7a-b: The front and back of the Cairo astrolabe in the tradition of al-Mizzi (#4164). [Photos originally from the L. A. Mayer Memorial Collection, Jerusalem, courtesy of the late Alain Brieux, Paris.]

arrangement. The scale of the ecliptic is divided for each 6° (without labels). The star-pointers are either talon-shaped or flame-shaped. The 32 (= 11 + 5 + 8 + 8) stars represented are as follows:

dhanab qayṭus	*rijl al-ghurāb*
ra'ʾs al-muthallath	*al-aʿzal*
[jasad] qayṭus see below	*al-rāmiḥ*
al-jadhmāʾ	*simāk al-zubānā*
al-ghūl	*awsaṭ thalāthat al-jabha*
ʿayn al-thawr	*al-fakka*
al-ʿayyūq	*ʿunuq al-ḥayya*
al-yusrā	*al-ḥawwāʾ*
al-yad al-yumnā	————
al-yusrā	*al-wāqiʿ*
al-rijl al-yumnā	*al-ṭāʾir*
————	*dhanab al-dulfīn*
al-ʿabūr	*al-ridf*
al-shaʾāmiya	*saʿd nāshira*
rukbat al-dubb	*fam al-[faras]* see below
al-fard	*janūbī sāq al-dālī*
qāʿidat al-bāṭiya	*al-mankib*
al-ṣarfa	
————	

The components of two star-names are written incorrectly: the [*jasad*] of *qayṭus* is written *ḥ-ʿ d*, the last two consonants being unconnected, and al-[*faras*] is written *al-ʿ-r-s*. This is surely an indication that the engraving was not done by the master al-Mizzī. There are no construction marks on the back of the rete.

The mater and two plates bear altitude circles for each 6° and azimuth circles for each 10° above (+) or below (-) the horizon. The arguments for the former are between the two outer circles and those for the latter are between the horizon and the first altitude circle and then around the rim of the plates (or beneath the horizon and the "crescent" in the case of plate 1a). The seasonal hours are numbered in *abjad* notation and the words *al-maghrib* and *al-mashriq* are engraved below the horizon. The latitudes served are:

M	21°	+	13;17^h	[0]
1a	30	-	**14;17**	see below
2a	32	+	14; 6	[0]
2b	33;27	+	14;14	[0]
1b	36	+	14;27	[-1]

The lengths of daylight are based on al-Mizzī's distinctive parameter 23;33°, and the distinctive value 33;27° for the latitude of Damascus was also used exclusively by him (and his emulators).

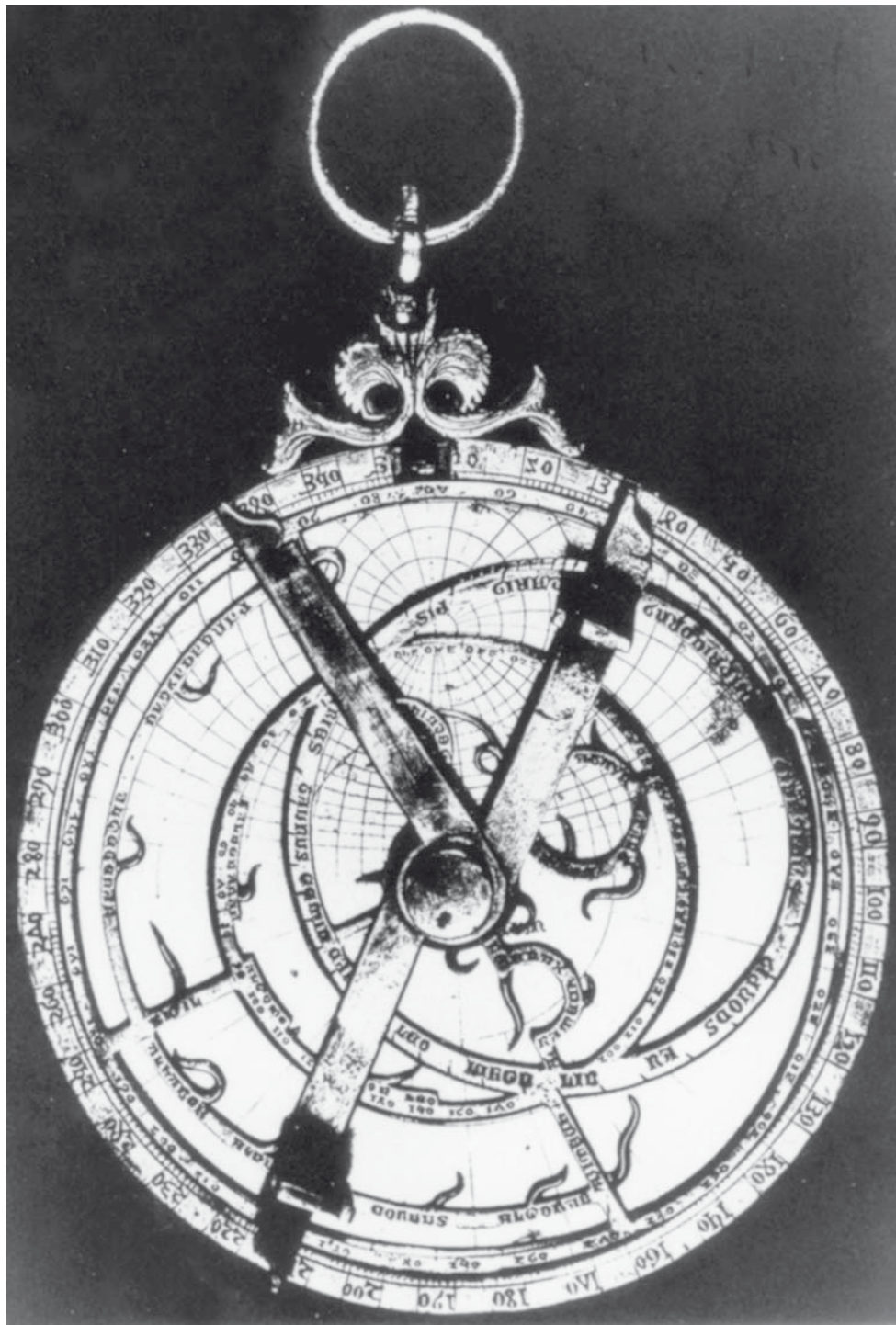



Fig. 7c: The astrolabe of Petrus Raimundus, made in Barcelona in 1375 (#3053). One may wonder whether the inspiration for the double semi-circular frames on the equinoctial bar and the circular frame on the upper vertical bar was in earlier Mamluk instrumentation. Here, in addition, we have a complete circular frame for the celestial equator and a large concentric semi-circular frame just inside the lower perimeter. See further the text to n. 21 in **XV-1**. [Object in the Museum of Fine Arts, Boston. Photo courtesy of the late Alain Brieux, Paris.]

The daylight for latitude 30° is in error: it should be 13;57^h. Apparently, the engraver combined an error of 14 for 13 (difficult to explain) and of 17 for 57 (easy to explain). In any case, al-Mizzī himself would have known better. The plates were clearly intended to serve Mecca, Cairo, Jerusalem, Damascus and Aleppo. The peg on plate 2 is broken off, and there are traces of solder at its base. Both plates are slightly thinner than the mater, each being just less than 1 mm thick.

The back bears a *shakkāziyya* grid. The surrounding scale is divided 5°/1°-5° as four altitude scales, and there are curves for each 5° of both arguments (with no ascension curves for the last 5° of declination). The ascension arguments are written inbetween the declination curves for 25° and 30°. There are no markings for the ecliptic. With the alidade having no scale—see below—the *shakkāziyya* markings serve no useful purpose.

The alidade, which appears to be original, is straight and has clef-shaped ends. The disc around the central hole has a circular "bite" taken out of it, which seems to be original. The sights have two holes, the lower one larger than the upper one. The pin has a low cylindrical head and the wedge is a rectangular piece of metal slightly thicker at one end.

Commentary
This is an interesting example of an unsigned astrolabe with a rete-design not attested elsewhere, whose milieu can be established simply by the parameters used on one of the plates. Certain medieval European astrolabes display the same double semi-circular frames on the equinoctial bar and circular frame on the upper vertical bar: see **Fig. 7c** for one example.

Later additions
There is a curious (or rather, absurd) boomerang-shaped piece of metal loosely attached by a nail at the bottom of the outer edge, which must be a later addition.

7* An astrolabic plate for multiple latitudes

International Instrument Checklist #4038
Berlin, Staatsbibliothek, Preußischer Kulturbesitz, Orientabteilung: Sprenger 2049. Formerly in the collection of the great orientalist Alois Sprenger (1813-93) (Fück, *Arabische Studien in Europa*, pp. 176-179). Earlier provenance uncertain (Sprenger travelled widely in the Near East).
Brass. Diameter: 115 mm.
Bibliography: *London SM 1976 Exhibition Catalogue*, p. 115 (no. 54), contains a brief description of this "simplified astrolabe" with "a certain eclecticism ... in its design", in which, however, the complex nature of the markings is overlooked.

This is a most unusual astrolabic instrument of considerable interest. Its sophistication leads me to suppose that it was made by one of the Damascus astronomers of the early or mid-14th century.

The instrument consists of a single plate engraved on both sides, each quadrant serving one specific latitude (if not two). The distinctive *kūfī* engraving differs from those on other signed instruments from 14th-century Damascus.

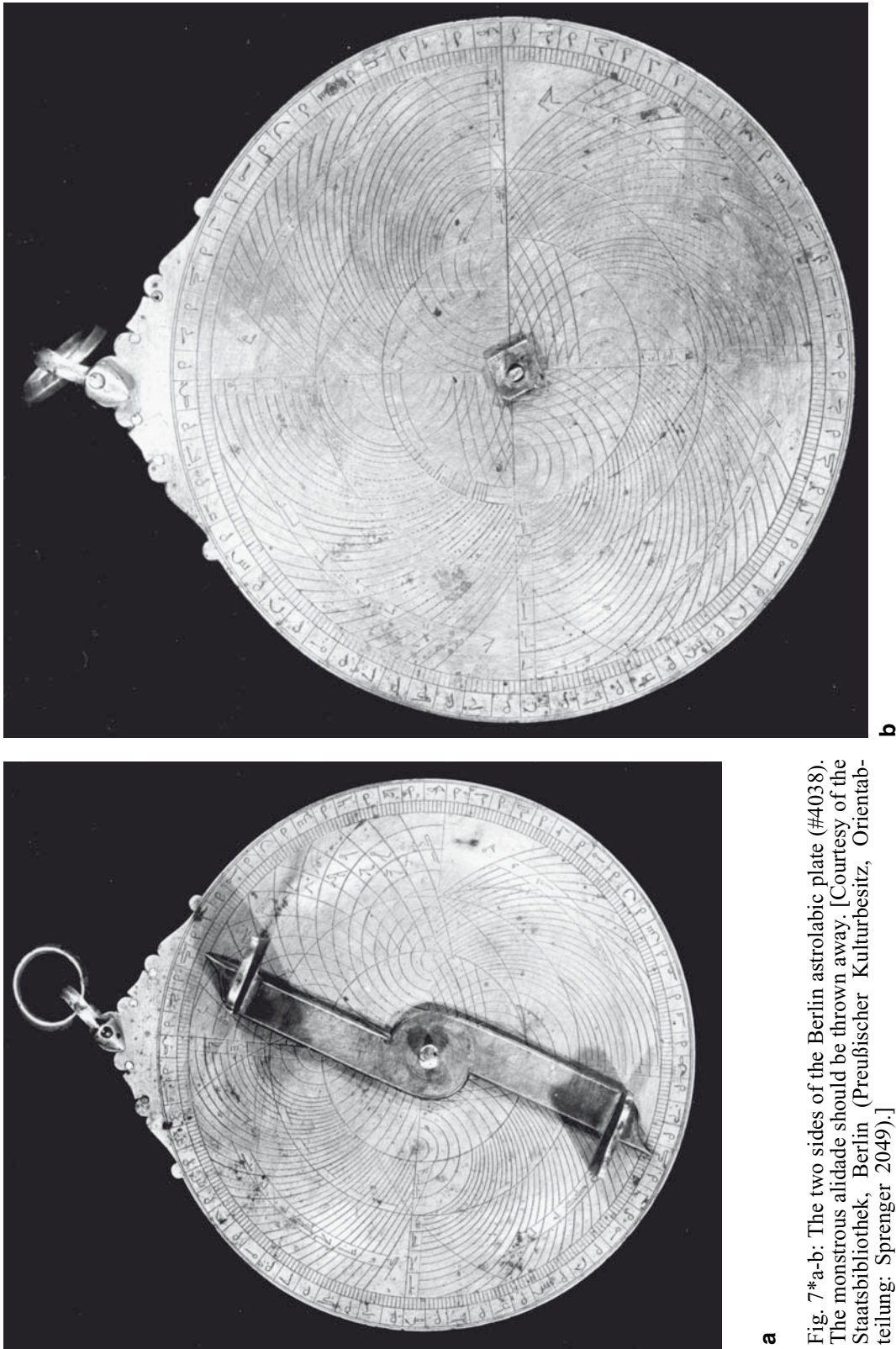
b

a

Fig. 7*a-b: The two sides of the Berlin astrolabic plate (#4038). The monstrous alidade should be thrown away. [Courtesy of the Staatsbibliothek, Berlin (Preußischer Kulturbesitz, Orientabteilung: Sprenger 2049).]

The throne is low and lobed on each side, and there is an additional, rather remote lobe at each of its extremities (as on 14th-century French astrolabes). The outer scales are divided 5°-1°/5° from 0° to 90° clockwise in each quadrant.

I label the quadrants on **Fig. 7*a** as Q1-4 $({}^{1}{}_{2}\oplus{}_{3}{}^{4})$ and those on **Fig. 7*b** as Q5-8 $({}^{5}{}_{6}\oplus{}_{7}{}^{8})$ and consider them in order of increasing latitude. The markings in the various quadrants are by no means the same, those in Q4 actually serving two separate latitudes. In each quadrant the markings are bounded by the circle for the winter solstice, so that we are dealing with a standard astrolabic projection. Within the circle for the summer solstice, altitude circles are engraved only for each 6°.

Q1 22° altitude circles for each 2° up to a limit (L) of 66° between the solstitial circles and for each 6° up to the zenith. The altitude scale is framed as on the plates of al-Khujandī (**XIIIc-9**).
Q4a 24° altitude circles for each 6° between the solstitial circles.
Q4b 27° as on Q4a, using the other axis as the meridian.
Q2 30° as in Q1 with L = 60°, but in addition altitude circles for each 6° folded over the east-west line for northern declinations greater than the obliquity ($\Delta > \varepsilon$).
Q5 33° as in Q2 (also with L = 60°). On the scale in this quadrant see below.
Q8 36° as in Q2 with L = 60°.
Q7 39° as in Q2 with L = 54°.
Q6 41;30° as in Q2 with L = 72°
Q3 45° as in Q2 with L= 42°.

There are markings for the ecliptic in Q3 and Q6, as on a standard astrolabic quadrant, which would serve all four quadrants on each side. The ecliptic is with dots for each 2°, three dots for each 10° and a short line for each 30°. The quadrant Q5 for latitude 33° is fitted with a scale marked non-uniformly 5°-1° around the circle for the summer solstice displaying a function that is not identified, and for which I have no explanation. The function behaves reasonably for arguments 0°-75° (measured counter-clockwise against the outer scale) but then appears to "peter out".

The latitudes selected render the instrument "universal" after a fashion, but also useful for an astronomer in the Mamluk realms. I find it surprising that 22° rather than the standard 21;30° (**II-10.8**) is used for the markings that would serve Mecca, but then again, the choice of 33° means there are no markings for 33;30°, the accepted value for Damascus (**II-10.1**). We have markings for each 3° of latitude from 24° to 39°, then 41;30°, which is clearly intended to serve Constantinople (**II-14.3**), then for 45°, for which perhaps no specific locality was intended. The following climates are served:

C2 (24°) C3 (30°) C4 (36°) C5 (41;30°) C6 (45°),

and also boundaries:

C2/C3 (27°) C3/C4 (33°) C4/C5 (39°).

The markings are of the type labelled *maṭwiya*, "folded", in medieval scientific Arabic (see also **5**). al-Mizzī (see **6-7**) authored a treatise on the astrolabic quadrant with folded altitude circles, that has not been studied.[14] We have noted that there is an ecliptic scale for each side of the instrument. Thus, to use the nine sets of markings for the sun (*i.e.*, the markings between

[14] *Cairo ENL Survey*, no. C34, and *Cairo ENL Catalogue*, II, §4.6.31.

the solstitial circles), one needs nothing more than a thread attached at the centre and fitted with a movable bead (as on a standard astrolabic quadrant). However, the maker also undertook to include markings above the limiting altitude of the sun at the summer solstice (at first sight, not a particularly good idea), taking trouble even to mark the lower altitudes for such declinations by folding them over the east-west line to fit on the appropriate quadrant. So maybe the plate was originally fitted with a rete bearing a few star pointers (and another ecliptic?)? However, maybe the maker had conceived something that would surprise us even more. Certainly, he was in full control of his subject. More work needs to be done on this important piece.

8 The most spectacular sundial of the Islamic Middle Ages, constructed for the Umayyad Mosque in Damascus

8.1 The sundial constructed by Ibn al-Shāṭir and dated 1371

International Instrument Checklist #7318 (original) and #7319 (copy).
Damascus, garden of the Archaeological Museum (fragments of the original), and Umayyad Mosque, main minaret (al-Ṭanṭāwī's copy).
Marble (metal gnomons missing on original). Length: 2.06 m. Width: 1.01 m.
Bibliography: Rihaoui, "Inscription inédite" (on the inscription); Janin, "Cadran solaire de Damas" (detailed description); King, "Astronomy of the Mamluks", p. 547; King, "Strumentazione", pp. 186; article "Mizwala" in EI_2, pl. XIX; and a second description in *Paris IMA 1993-94 Exhibition Catalogue*, p. 439 (no. 334). A new study of the curves for twilight is Savoie, "Les crépuscules sur les cadrans solaires islamiques".

In 1958 three pieces of marble were discovered in excavations of the drainage system of the Umayyad Mosque: these were substantial fragments of a magnificent sundial by Ibn al-Shāṭir. The original had apparently broken around 1240 H [= 1824/25] whilst the Damascus *muwaqqit* Muḥammad ibn Muṣṭafā al-Ṭanṭāwī[15] was trying to adjust it. A copy prepared by al-Ṭanṭāwī in the year 1293 H [= 1876/77] is still *in situ* on the Minaret of al-ʿArūs in the Umayyad Mosque. The fragments of the original grace the garden of the Archaeological Museum. Copies on paper were available in the 1970s, but my copy disappeared during a seminar at New York University. For the Paris Exhibition a copy in plaster was prepared but has since self-destructed.[16]

[15] *Cairo ENL Survey*, no. D123.
[16] The question of a fee for my services to the Paris Exhibition arose, and we settled on a replica of the sundial of Ibn al-Shāṭir. At the time I had just acquired an old farmhouse in rural France, and what better place to install a sundial than on the terrace? A Paris moving company wanted several thousand francs for moving the enormous and weighty box; I settled on FF 600 with a provincial mover. The box arrived and was dumped in front of our house. I paid another FF 600 to six local labourers to schlepp it up a flight of stairs to the terrace, and then we removed the box. The copy was not particularly well executed, and my wife was relieved that we had decided not to install the thing indoors. It was not clear what material the beast was made of, but it was not concrete. It was about 50 cms thick. Since we had to leave forthwith for Frankfurt, I covered it carefully with plastic. A couple of weeks later my German neighbour, Günter Gloth, who checks our house during bad weather, phoned me in Frankfurt with the question: "Wie wichtig ist Dir eigentlich das Ding auf der Terasse?", which was a kind way of telling me: "That thing on your terrace has had it." By the time I saw it a few weeks later, the engraved part of the top of the sundial looked like Roquefort cheese. It took me several hours to break the monster into pieces small enough that I could transport them to the local building materials dump. I still have the metal gnomon.

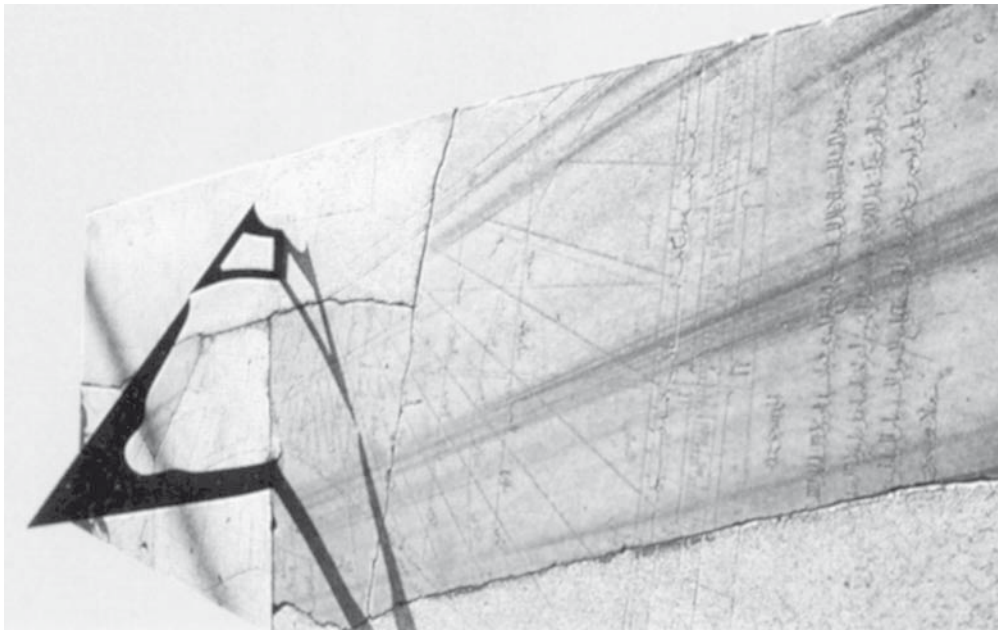



Fig. 8.1: Fragments of the original sundial of Ibn al-Shāṭir (#7318). [From *Paris IMA 1993-94 Exhibition Catalogue*, p. 439.]

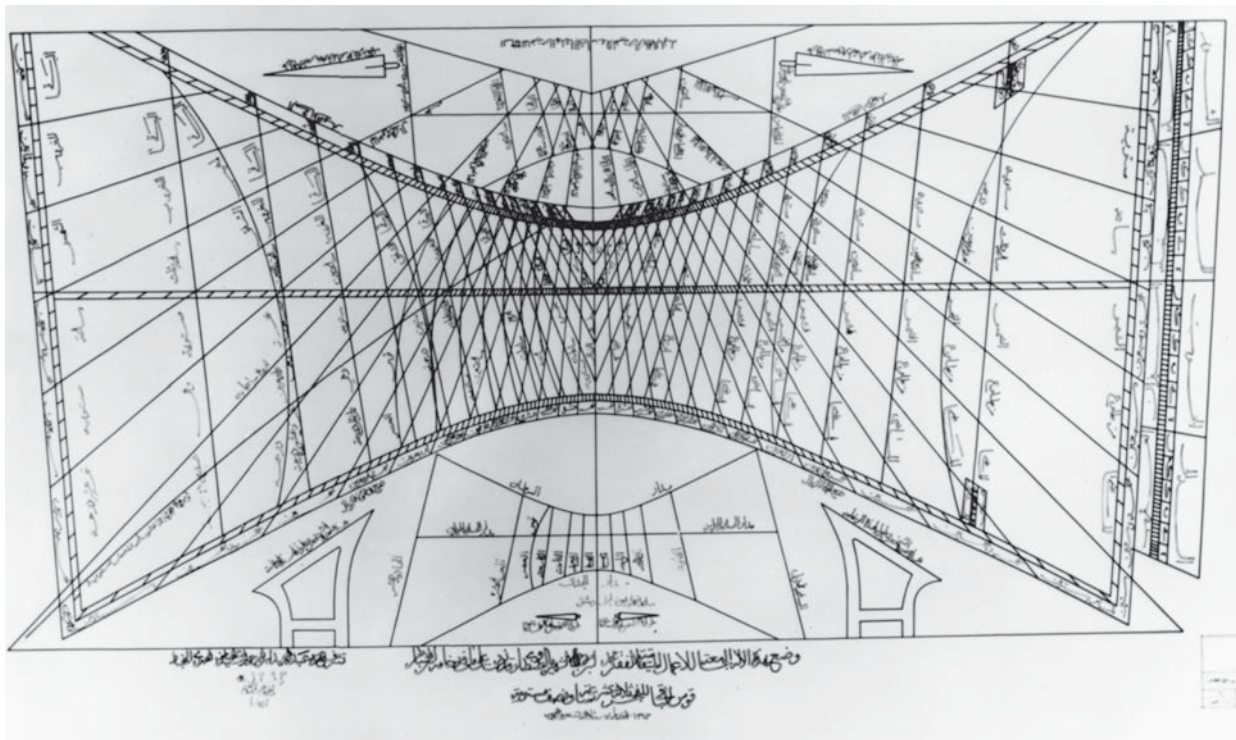



Fig. 8.2: The magnificent sundial of Ibn al-Shāṭir as reconstructed by al-Ṭanṭāwī (#7319). [Courtesy of the late Frans Bruin, Beirut.]

The original instrument bears an inscription that is no longer fully intact. What is legible translates as follows:

وضعت الآلة الجامعة للأعمال الميقاتية برسم الجامع الأموي في دولة سيدنا ومولانا السلطان الملك ... | سيف الدنيا والدين
منجك كافل الممالك الشريفة بالشام المحروس أعزّ الله أنصاره بنظر مولانا العبد ... | بيد مصنّفها علي بن إبراهيم محمد
الأنصاري الموقت بالجامع الأموي الشهير بابن الشاطر عفا ... | سنة ثلاث وسبعين وسبعمائة

"This instrument for all of the operations of astronomical timekeeping was made by order of the Umayyad Mosque during the reign of our Lord and Master, the Sultan and King, [al-Ashraf Shaʿbān] ... ... Sayf al-Dunyā wa-'l-Dīn Manjak, Governor-General of the noble possessions in Damascus, (city) protected by (God)—may God strengthen his assistants. (This was) under the surveillance of ... ... at the hand of its constructor ʿAlī ibn Ibrāhīm ibn Muḥammad al-Anṣārī, the *muwaqqit* at the Umayyad Mosque—may [God] forgive him—in the year seven-hundred and seventy-three [= 1371 A.D.]."

As we shall see, Ibn al-Shāṭir achieved his goal admirably.

The complex of markings consists of three sundials, there being one smaller one above the main one and another below it. The lower one is typical of the simplest variety of Islamic horizontal sundial. The length of the vertical gnomon is indicated twice below the markings, which consist of the equinoctial and solstitial shadow-traces and lines corresponding to the 1st to the 11th seasonal hours of daylight, as well as a curve for the *ʿaṣr*. A short line perpendicular to the meridian defines the base of the gnomon.

The upper sundial bears similar basic markings (although the summer solstitial shadow-trace is approximated by straight lines) and the vertical gnomon, whose length is indicated on each side of the markings, is about twice as long as the first. The hour-lines now serve the equinoctial hours after sunrise (before midday) and before sunset (after midday); they are extended to serve the hour markings on the larger sundial (see below). The gnomon must be removed and replaced by a more complicated one in order to use the third sundial.

The gnomon for the main markings is trapezoidal in shape, the inclined side being aligned so that it points towards the celestial pole. So the higher end has the same length and stands in the same position as the conical gnomon for the second sundial. There are solar scales on either side of the instrument outside the outermost markings (see below). These are ingeniously devised so that one could read the solar longitude to the nearest degree as the shadow falls on at least the right-hand scale. The complex series of markings would confuse any but the most competent astronomer. The markings are bounded by the shadow traces for the solstices, and crossed by that for the equinoxes. On each of these there are scales on which each 20 minutes is subdivided into 4 minute-intervals. The markings, which all bear appropriate identifying inscriptions, include the following:

a) straight lines showing each 20 minutes before and after midday;
b) straight lines for each 20 minutes before sunset (after midday);
c) straight lines for each 20 minutes after sunrise (up till midday);
d) a set of seven curves displaying each 20 minutes up to the *ʿaṣr*, from two hours before the prayer up to the prayer-time itself; and

e) two sets of two curves showing specific times relating to morning and evening twilight, namely, 45° and 60° after the former, and 60° and 45° before the latter, as well as a solitary, somewhat optimistic, curve marking the time 13;30 hours before dawn. (These curves have been studied by Denis Savoie.)

In brief, the complete set of markings enables the user, in addition to following the passage of time in equinoctial hours, to regulate time with respect to each of the five daily prayers. *This is the most sophisticated sundial known from before the late European Renaissance.* Only recently have we discovered anything similar: see **Fig. X-7.2.8**.

8.2 A copy made by al-Ṭanṭāwī in 1876/77

See **8.1** for details.

The inscription on the copy by al-Ṭanṭāwī translates as follows:

وضع هذه الآلة الجامعة للأعمال الميقاتية الفقير محمد بن إبراهيم الشهير بالطنطاوي وقد زدت على ما في رخامة ابن الشاطر | قوس الباقي للفجر ثلاثة عشر ساعة ونصف مستوية | ١٢٩٣ ألف ومائتين وثلاث وتسعين هجرية

"This instrument (*āla*) for all the operations of timekeeping was constructed (*waḍaʿa*) by Muḥammad ibn Muṣṭafā known as al-Ṭanṭāwī. I added to what was on the horizontal sundial (*rukhāma*) of Ibn al-Shāṭir the curve for thirteen and one-half equinoctial hours before daybreak. (This was in the year) 1293, one thousand, two hundred and ninety three, Hijra [= 1876/77]."

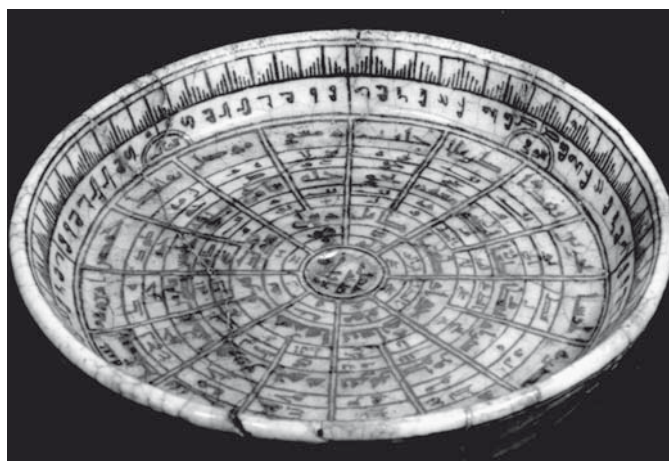
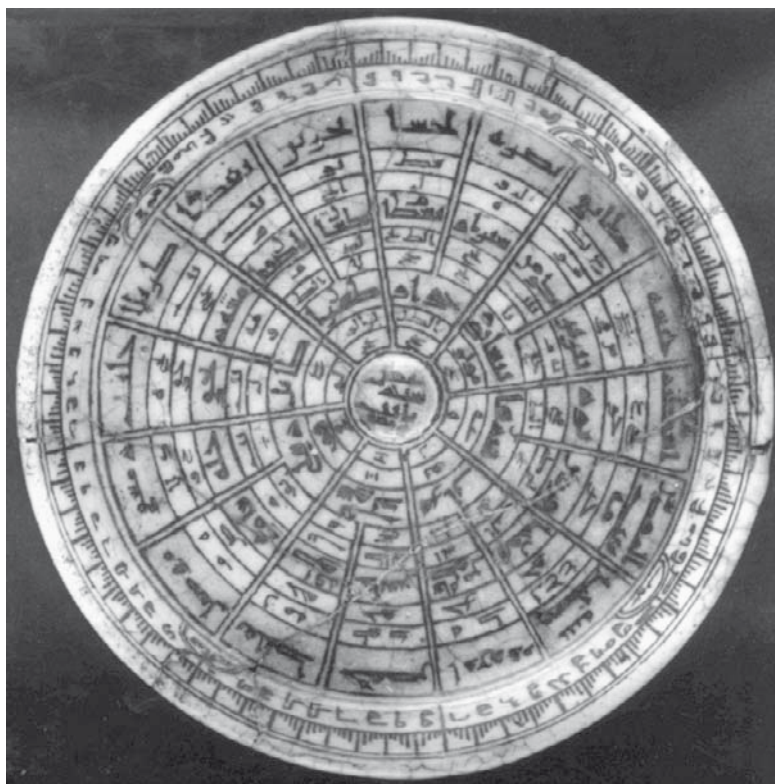
To the left of this is another inscription that is not fully legible

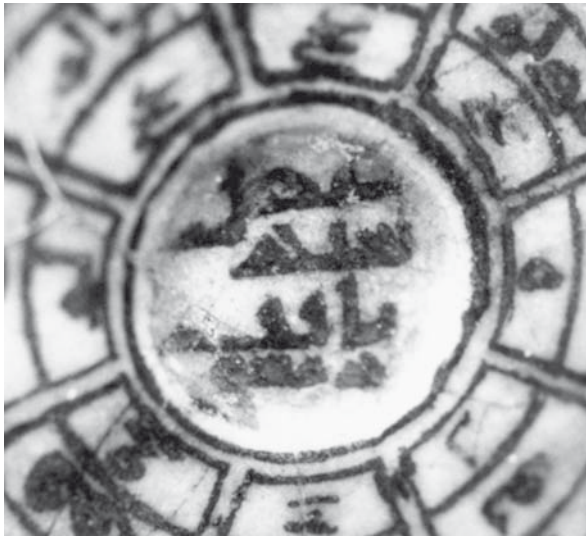
تشرّف بتحريره (؟) عبد المجيد ابن المرحوم السيد عثمان الحموي النجار ١٢٩٣

"ʿAbd al-Majīd, son of the late al-Sayyid ʿUthmān al-Ḥamawī (from Hama) al-Najjār (the carpenter/craftsman), supervised laying it and securing it in the right position (*tasharrafa bi-ḥafrihi* (?)) in 1293."

9 A ceramic compass-bowl by Thābit, datable *ca.* 1518

International Instrument Checklist #8026.
Damascus, Archaeological Museum, inv. no. T123/A1727.
Ceramic, varnished blue and beige background, inscriptions in black. Diameter: 19 cm. Height: 3 cm.
Bibliography: The first description of this instrument, based on deficient photographs, is in *Paris IMA 1993-94 Exhibition Catalogue*, pp. 440-441 (no. 336); more information is in King, *Mecca-Centred World-Maps*, pp. 110-114, 168-170, and 478-480.

This instrument is unique in that it is the only known qibla-dial in which the compass-needle (now missing) would have floated on water or some other transparent liquid. The Yemeni Sultan

a

b

Figs. 9a-b: The Damascus compass-bowl (#8026). The geographical data was clearly copied from another instrument of the same kind by somebody who had no understanding of it whatsoever—see further **Fig. 9e**. [Courtesy of the Institut du Monde Arabe, Paris.]

Figs. 9c-e: Some details of the signature, the much corrupted qibla-values, and part of the inscription around the outer rim. [Photos by the author.]

al-Ashraf (*ca*. 1290) has left us with a description of such an instrument, albeit in brass.[17] On account of the *kūfī* inscriptions the piece has the appearance of being much older than it is. The inscription at the centre of the inside of the bowl reads:

عمل | شيخ | ثابت | بدمشق

"Made by Shaykh Thābit in Damascus."

This Thābit is unknown to us. His work, however, is fully within the tradition of Syrian blue-and-white ceramic tiles, which started in the 15th century.[18] There are two inscriptions on the outside of the rim, for which, for lack of a complete set of photos, I cannot provide the Arabic texts. One, in the four cartouches, translates:

> "Made for the King, the victorious, the just, *khāqān*, son of the *khāqān*, king of the two earths and the two seas and servant of the two noble sanctuaries (*sc*. Mecca and Medina), the Sultan Salīm—may God prolong his reign. Amen."

[17] On this see now Schmidl, "Early Sources on The Compass", and on al-Ashraf and his instruments see **XIVa**.
[18] Meinecke, "Syrian Tiles", and further examples in *Paris IMA 1993-94 Exhibition Catalogue*, pp. 456-461.

Since the Ottoman Sultan Selim conquered Syria in 1516 and died in 1520, we can date this piece *ca*. 1518. The other inscription is in a larger script between the cartouches. It deals with the use of the instrument for finding the qibla, but the text is not currently (Dec. 2004) available to me.

The inside of the rim bears a scale divided for each 5° and subdivided into 1°-intervals, a truly remarkable achievement for a craftsman working with ceramic. The 5°-divisions are labelled from 5° to 90° in each quadrant, starting at the north- and south-points and running to the east- and west-points. The cardinal directions are identified by their names on a double semi-circular frame. The geographical information is contained in eight sectors, of which the outer part is subdivided into two sub-sectors, so that each sector serves five localities. Their names are given together with their qiblas, usually to the nearest degree, and the quadrants of the horizon to which these qiblas apply, with abbreviations that are not a little confused. The geographical data on the bowl, which I label DMS, are so corrupt as to be barely intelligible, and are, for any practical purpose, quite useless. Neverthess, detailed investigation reveals a connection to a 15th-century Central Asian source: see **Table 1**.

Table 1: The geographical information (DMS) on the Damascus qibla-bowl (#8026)

Notes: The information recorded on this piece is a total disaster; my interpretation is merely aimed at reducing its totality. The information is arranged in three parts, the name of the locality and two sets of numerical and/or alphabetic information. What was originally intended with the latter was a qibla-value in degrees and minutes and a direction, NE, NW, SE or SW, indicated by (not necessarily consistent) Arabic abbreviations (*sh-q* for *shamāl-sharq*, *etc*., to *j-gh* for *janūb-gharb*). An asterisk denotes the division between the inscriptions. A black dot • denotes a letter that is illegible in the "entries" and ÷ a letter that defies interpretation. A dash (-) connects letters written together as a ligature in Arabic. A slash (/) separates two possible readings. A derivation of a copyist's error from a probable original value is indicated by <. The qibla-values, where they can be reasonably interpreted, have been compared with those in TMR and also, as an example of the corrupt parallel tradition, MZB; clearly, cases where the values correspond to entries in those sources which have substantial errors are of particular interest. Δq denotes the error in the minutes of the qibla values, when compared with recomputed values based on the coordinates of TMR. For TMR and MZB see *ibid*., pp. 456-477 and 501-505. For references to other sources cited, see King, *Mecca-Centred World-Maps*, pp. 478-480.

	Locality	Entry	Interpretation	Comments
1	Mosul	h m * ṣ	5;40 • < 0;40 •	TMR69/MZB/GRZ: **0**;42° SE; QYNX7: **0;40**°
2	Sawa (?) / -Samarra (?)	• * x-w	5/-4 * 1/-5-6 < ••;16	Only *sīn-alif* in the name is clear, thereafter follows *m-w-h*. TMR133 has 29;**16**° for Sawa and TMR101 has 7;56° for Samarra (TMR115 with 48;43° for Shapur is probably not relevant)
3	Delhi	f-w / f-q * q	86/-8• * • < 87 * •	TMR247: **87**;34° SW; MZB: **87**;26°
4	Hilla	x-b * ÷	12 * •	not in TMR/MZB; THR5 has 12;5°
5	Damascus	k l-ʾ * ḥ q	20;31 SE < **30;31** SE	TMR38/MZB: **30**;**31**° SE (Δq = +1)

6	Aleppo	x-ḥ h * ḥ-q	18;5 SE	TMR43: **18**;**3**3° SE; MZB: **18**;29°
7	Najaf	y-b * l	12;30	TMR102/MZB: **12**;31° SW for Kufa; THR2 has **12;30°** for Najaf
8	Kabul	ʿ * l-w	70 * 36 (?)	TMR261: 69;57° SW; MZB: 53;40°
9	Meshed	m-h * q	45 * E/6	TMR161: **45**;6° SW (Δq = -3); MZB: **45**;23°;
10	Kerbela	y-b * ʿ-ḥ	12 SW	TMR104: **12**;46° SW and MZB: **12**;45° for Baghdad
11	Baghdad	y-b * s (?)	12 * •	TMR104: **12**;46° SW and MZB: **12**;45°
12	Isfahan	m * ʾ-l-ṭ	**40;29**	TMR138: **40;29°** SW (Δq = 0); MZB: 40;45°; MZT: 40;15°
13	**Tehran**	l-r ʾ-l-w * ʿ-ḥ	**37;26** SW	TMR141/MZB: **37;26°**; TMR*: 36;26° SW (Δq = 0)
14	Kashan	l-d * l-ʾ	**34;31**	TMR139/-MZB: **34;31°** SW (Δq = 0)
15	Bahrein	x-w * ʾ-l-ḥ	56;23 < **57;23**	TMR26: **57;23°** SW (Δq = 0) for Hajar; not in MZB
16	Lahsa	s-ṭ * l	**69;30**	TMR27: **69**;28° SW (Δq = 0); MZB: **69;30°** (+2)
17	Bistam	ʾ-l-ṭ x-ḥ * ʿ-ḥ	29;1/5-3 < **39;53** SW	TMR155: **39;53°** SW (Δq = +1); MZB: **39;13°**
18	Khuwar	ʾ-l-ṭ-r * ʿ-ḥ	29;• SW	TMR142: 34;38° SW; not in MZB
19	Sabzawar (?)	x-ḥ * ḥ-ḥ	1/5-8 * 1/5-8 (???)	TMR159 has 44;12°
20	Basra	l w * h	30 * •	TMR106 has 37;59°
21	Taif	ʿ l-ṭ * s-w	•;39 NW < **0;39** NW	TMR24: 0;**39**° NW [!!]; q* = 42;52° (!!); not in MZB
22	Kirman	s-x * x-ʾ	62;1/-5-1	TMR218: **62**;56° SW for Bardsir; MZB: **62;51°**
23	Nishapur	m-w l-w * ʿ-ḥ	46;36 SW	TMR160/MZB: **46**;**2**5° SW
24	Tabriz	x-h m * ʿ-ḥ	1/-5-5;40 SW <	
			15;40 SW	TMR83/MZB: **15;40°** SW (Δq = 0)
25	Ethiopia	• - • (?) -ṭ *		
		s-r q-y / s q	• - • - • * NE	TMR11/MZB: 82;25°; TMR*: 42;25° NE for Jarmi - note that ϕ: **9**;30°
26	Alexandria	x-ḥ ʿ * ḥ-w	1/-5-3/-8 • * SE	TMR14: **5**9;24° SE; not in MZB
27	Yazd	m-ḥ * ʾ-l-ṭ	**48;29**	TMR122: **48;29°** SW (Δq = +2); MZB: 48;28°
28	Qandahar	ʿ-h * h	75;5	TMR239: **75**;0° SW (Δq = +1); MZB: **75;5°**
29	Qazwin	l-r k-h * ʿ-ḥ	37;25 SW < **27;34** SW	TMR134/MZB: **27;34°** SW (Δq = -1)
30	Jerusalem	m-h * ḥ-q (?)	45;•• SE	TMR29: **45**;43° SE (Δq = +3); not in MZB
31	Constantinople	l ḥ ʿ * j-q	38; • SE	TMR52/MZB: **38**;17° SE
32	Hamadan	ʾ-l-b /- k-b * x-w	**22;16**	TMR*131: **22;16°** [0] (TMR has 22;17°)
33	Herat	x-w * l	5• * •	TMR169: **5**4;5° SW; MZB: **5**5;0°
34	Kirmanshah	ʾ-l-ḥ * •		
		(illegible)	23; •	TMR125: **23**;18° for Qirmisin; not in MZB
35	Erzerum	h k * ḥ-w	5;20 SE < **0;30** SE	TMR55/MZB: **0;30°** SE
36	Homs	k-w d * ḥ-w	26;• SE	TMR*39: **26**;17° SE (Δq = 0) (TMR has 27;17°); not in MZB
37	Hulwan	k-ʾ l-w (?) * ʿ-ḥ	21;36 SW < **21;16** SW	TMR124: **21;16°** SW (Δq = 0)
38	Sarandib	| • | * | • |	• * •	TMR243/MZB: 70;12° NW
39	Kufa	y-b * s (?)	12 * •	TMR102/MZB: **12**;31° SW
40	Baalbek	r m-h * ḥ-s	7;4• S•	TMR37: 2**7**;**4**9° SE; not in MZB

Note to nos. 4 and 37: The signs ÷ and | • | appear to indicate numbers that the maker simply could not read and realized as much. In no. 36 the second one is written sideways.

Elsewhere[19] I have shown that there was a geographical table compiled in the mid 15th century, probably in Kish near Samarqand, that contained values for each of 274 localities of the longitude (L), latitude (ϕ), qibla in degrees, minutes and seconds (q), and distance from Mecca in degrees and minutes (d). I labelled this table TMR* (from Timurid), the asterisk denoting the fact that it does not survive in its original form. It survives only in a recension, TMR, by an astronomer of Najaf *ca*. 1700, one ʿAbd al-Raḥīm ibn Muḥammad, in which the qibla values are rounded to minutes and the distances to Mecca converted to *farsakh*s and sexagesimal fractions thereof. I further showed that there was a corrupt version of this table in circulation. This version as it occurs on the Berlin astrolabe of Muḥammad Zamān I have labelled MZB. The original table and the corrupt version were used by various Safavid instrument-makers in Isfahan and Meshed for the gazetteers that they engraved on their instruments; in particular, the data on the original table was used on their Mecca-centred world-maps for finding the direction and distance to Mecca.

Now some of the values on the Damascus bowl correspond to those in the *accurate version* of the main Timurid table, as represented by TMR.[20] Yet others correspond to those in the *corrupt version*, as represented by MZB.[21] I suspect that the data on the compass-bowl are taken from an Iranian table of values L,ϕ,q (and probably also d) for a limited number of cities that has not been preserved for us: perhaps it was such a table that inspired the compilers of TMR to produce a universal table with values of q and d computed properly.

There is, I believe, sufficient evidence to conclude that such qibla-bowls were in circulation in Central Asia and perhaps also in Iran in the 13th century, if not before. Certainly, they were known in Egypt and the Yemen by the late 13th century (see **X-9.2**). In any case, the Damascus bowl is a unique testimonial to an earlier (13th-15th century?) Central Asian tradition of instrument-making about which we know nothing except that the Damascus bowl is derived from it. That tradition is apparently quite distinct from the one that flourished in the second half of the 17th century in Isfahan and Yazd, where we again find magnetic compasses, but of a different kind.[22] Yet both traditions used essentially the same corpus of geographical data.

One may wonder what the Sultan Selim might have had done to Thābit if he had found out that the information on the qibla-bowl was quite useless. Clearly, Thābit copied it from another such bowl, on which the information was already corrupt. He would have done better to use the qibla values for Syria and Palestine computed by the 14th-century Damascus astronomer Shams al-Dīn al-Khalīlī (**II-10.9**), which are all accurate to within a few minutes: copies of these would have been readily available in Damascus.

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[19] King, *Mecca-Centred World-Maps*, pp. 149-186.

[20] For example, no. 25: Yazd has 48;29°, as in TMR (although, in fact, MZB has the yet more accurate value 48;28°), and no. 12: Isfahan has 40;29°, as in TMR (MZB is incorrect). No. 22: Tabriz has 15;40°, as in both TMR and MZB. No. 17: Bistam has 29;53°, whereas TMR has 39;53° and MZB may have 39;13° (reading uncertain).

[21] For example, no. 16: Lahsa has 7**9;30**°; TMR has 6**9**;28°, but MZB has 6**9;30**° (the error 70 for 60 is more difficult to explain than the difference in the minutes).

[22] See King, *Mecca-Centred World-Maps*, pp. 114-124.

10 An astrolabic quadrant for Damascus made by Muḥammad al-Ṣakāṣī al-Jarkasī in 1891/92

International Instrument Checklist #5012.
Acquired by the British Museum, London, by action at Christie's on 13.12.1996. Previously in various private collections. Acquired in Beirut *ca*. 1950.
Wood, with markings in black and red ink on paper, glazed. Radii: 133 and 110 mm. Thickness: 19 mm.
Bibliography: This instrument is illustrated in King, "Strumentazione", pp. 174 and 181 (pp. 18-19 of the English summary); *idem*, "Astronomical Instruments between East and West", p. 162; *idem*, "Making Instruments Talk", p. 7; *idem*, "Muwaqqits and Muezzins", pp. 312, 348 and 345; *idem*, "Islamic Astronomy", p. 168; the article "Rubʿ" [= quadrant] in EI_2, pls. XXXIV-XXXV, between pp. 574 and 575; and elsewhere. It is discussed in more detail in *Paris IMA 1993-94 Exhibition Catalogue*, pp. 442-443 (no. 337). On the month-names see Maier, "Romanische Monatsnamen", B, pp. 263-265. The fullest description is in *Christie's London 13.12.1996 Catalogue*, pp. 40-41 (lot 599), by this writer, which has been incorporated here.

This is a superbly-worked quadrant bearing astrolabic markings for the latitude of Damascus on the front and a highly sophisticated trigonometric grid on the back. Quadrants in wood survive in the hundreds from the Ottoman period of Islamic astronomy (*ca*. 1500 - *ca*. 1900). None is known that is as finely worked as this one. Although this instrument bears a late date, it is clearly representative of the culmination of the standard astrolabic quadrant in Damascus in the 14th and 15th centuries. However, no instrument of this sophistication survives from the earlier period. Also, the fact that most of the inscriptions are in a sophisticated *kūfī* script is indicative that these were copied from a much earlier instrument.

There are two feet on the side corresponding to the meridian; they are without sighting holes (as seems to have been common on Ottoman quadrants). The front bears a main outer scale divided for each 5°, then for each degree and half-degree and labelled for each 5° in both directions, upwards in black and downwards in red. Outside this is a non-uniform scale divided 5/1-5 up to 60 and marked *al-ẓill al-mabsūṭ* for shadows to base 12. Outside this is a scale divided for each 15°, with each 15°-interval subdivided into 12 equal parts, and labelled for the hours 12 - 1/11 - ... - 5/7 - 6 from the bottom to the top. The main markings consist of altitude circles for each 1°, black for each 5° and red inbetween, and azimuth circles for each 5°, black for each 15° and red inbetween. The southern ecliptic is divided for each 5° and subdivided for each 1°; the northern ecliptic is not divided (the markings on the former serve also the latter, with the help of the radial cord). There are additional curves for the first and second *ʿaṣr*, marked simply *awwal* and *thānī*, "first" and "second", as well as for morning and evening twilight (to be measured from the meridian) marked *f* for *fajr*, "daybreak", and *sh* for *shafaq*, "nightfall", the underlying parameters are 19° and 17° for the solar depresssion below the horizon. A curve that is discontinuous at the meridian is marked *khaṭṭ ʿīdayn*, "the curve of the two festivals", and serves to find the time of the community prayer on the two major Muslim festivals, and a curve that is discontinuous on the line drawn through the centre perpendicular to the meridian is marked *khaṭṭ imsāk*, "the curve of abstinence", and serves to find the time before daybreak in Ramadan when the faithful should start fasting for the day.
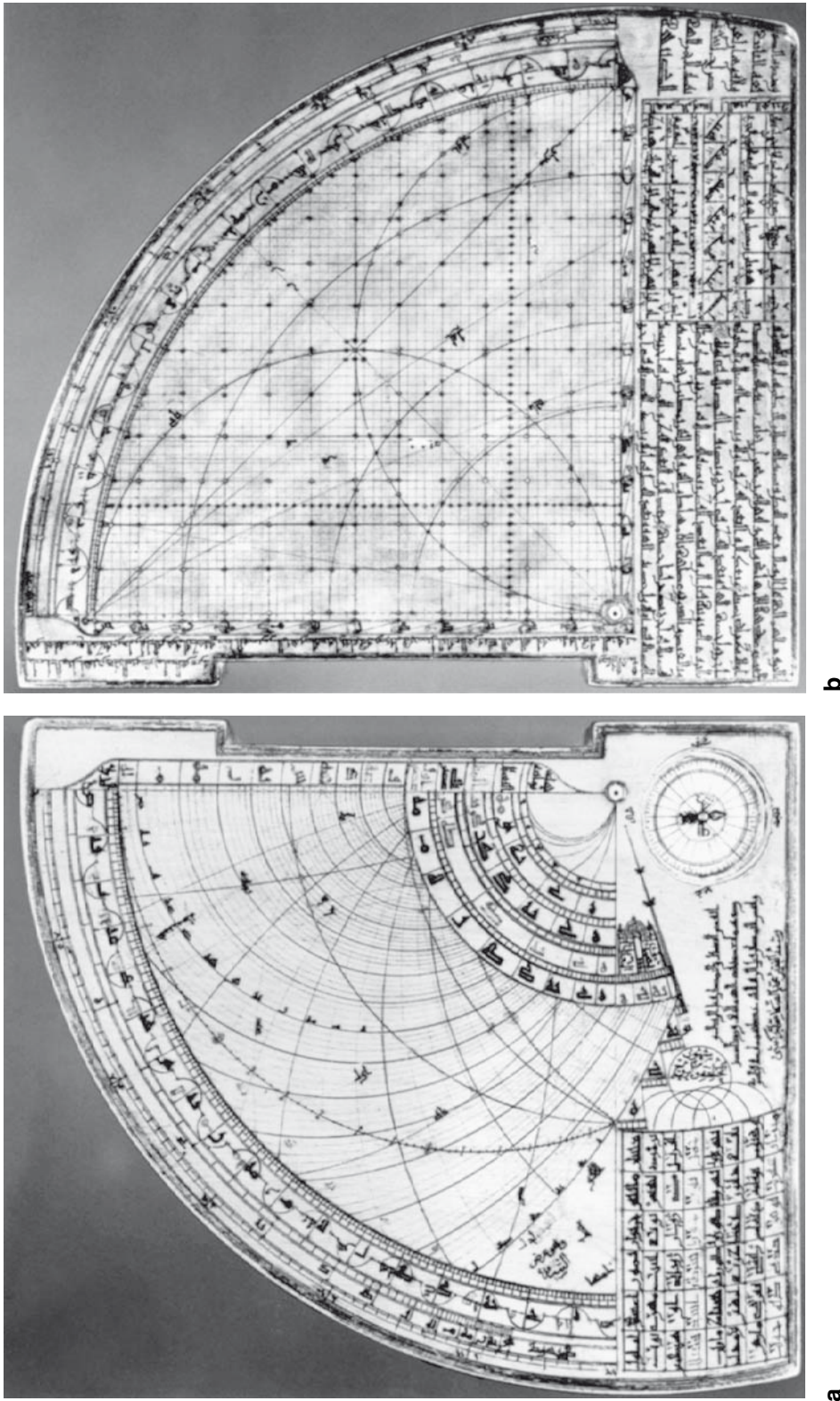
Fig. 10a-b: The front and back of the quadrant of al-Ṣakāṣī (#5012). [Courtesy of Christie's, London.]

Because this latter curve has been "folded" to fit on the space available there are extensive instructions stretching over both sides of the instrument describing how to find the time of abstinence. There is also a curve for finding the length of the seasonal hours (to be measured from the meridian) and marked *zamāniyya*, which is close to an azimuth curve (for about 19° east of south) displaying the qibla (local direction of Mecca) and marked *samt Makka*. A curve marked *ṣ* displaying a function (measured from the line perpendicular to the meridian) which has values of about 13° at the summer solstice and equinoxes and 14° at the winter solstice defies interpretation. The horizon is marked "The horizon for latitude 33;30°, which is the latitude of Damascus (*al-Shām*)". Inside the astrolabic markings are scales for finding the altitude of the sun at the first and second afternoon prayers (*ʿaṣr*), the solar declination, the half excess of daylight (the excess of half the length of daylight over 90°), and inside these is a very small universal horary quadrant with the hours labelled 1-6 on the outside.

Below the main markings is a magnetic compass marked with the cardinal directions on the outer rim and again at the centre (*gh* for *gharb*, "west" and *sh* for *sharq*, "east"). To the side of this there is an inscription in elegant Kufic related to finding the time of abstinence in Ramaḍān (see above and also below). Below this is another in elegant *naskhī*:

رسمه الفقير محمد الصكاصي الجركسي

"Drawn by *al-faqīr* Muḥammad al-Ṣakāṣī al-Jarkashī."

The epithet al-Jarkashī indicates that he was of Circassian origin,[23] and the meaning of al-Ṣakāṣī has not been determined. To the left of these inscriptions is a calendrical table labelled in bad Arabic "Different months and signs" (*shuhūr al-mukhtalifa wa-'l-burūj*). The information it contains is the following: (1) names of the Syrian months; (2) names of the Coptic months; (3) names of the months in French (!); and names of the zodiacal signs. Beside each of these names in (2) to (4), there is a number showing the correspondance to the first day in the corresponding Syrian months. The French names of the months are a surprising inclusion. They would be pronounced roughly:

ژانڤيى ڤڤريى مارس اڤريل مى ژوان ژويليى او سپطامبر اوكتومبر نوڤامبر ديسامبر

janvīé, fafrīé, mārs, afrīl, may, jū'ān, jū'īlīé, ū (simply an *alif* and a *wāw*),
saptambr, ūktūmbr, nūvmbr and *dīsāmbr*,

the "é" being somewhat forced in Arabic orthography (a final "*yā'*" is used), and *octombre* a reminder of certain medieval French dialects by assimilation to the other month-names late in the year.[24]

The back bears a standard sexagesimal grid (with radial axes divided into 60 units) with a palette of additional markings that are basically as follows:

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[23] See the EI_2 article "Čerkes" by Halil İnalcık, especially on their role in Mamluk and Ottoman society.

[24] On the use of *octembre* on medieval astrolabes from N. France, see Maier, "Romanische Monatsnamen", A, pp. 240-242, and King, *The Ciphers of the Monks*, pp. 138-140.

(1) two semi-circles on the radial axes as diameter, for setting the bead on the cord to the sine or cosine of an angle between 0° and 90°;
(2) three quarter-circles, the inner one for finding the solar declination as a function of solar longitude, and the outer two for setting the bead on the cord at the sine and the cosine, respectively, of the latitude 33;30°; and
(3) two perpendicular dotted lines and three intersecting rays (two non-rectilinear) providing alternative procedures for determining the altitude of the sun at the time of the mid-afternoon prayer (*ʿaṣr*).
(4) In addition there is an axial diagonal (marked *mīzān*), and a radius at argument 45° (the last is marked *sīn rāʾ*, for what reason is not clear). There are radial lines marked in red at arguments approximately $10^1/_2$° and $77^1/_2$°, the latter marked with the letter *sīn*. These markings have so far defied explanation.

Beneath these is a continuation of the instructions on the means of using the curve on the front of the quadrant for the time of abstinence in Ramadan, and next to this another calendrical table relating the 12 months of the Islamic calendar to their positions firstly in an eight-year solar cycle, an approximation used in Ottoman almanacs using the *māliye* calendar, and secondly in a standard 28-year cycle. (A detailed study of this table was prepared in 1994 by Silke Ackermann in Frankfurt.) In this table the year 1307 Hijra is given as the first year in the 28-year cycle, so that the instrument must date from around this time (see below). To the far left is the end of the inscription on the *imsāk*, ending " ... and the two curves (*sc*. the two parts of the curve) are for latitude 33;30°". Then follows a date ?07 where '?' could be 2 or 3 and there may or may not be an initial 1 (in red ink); the reading is clear, namely, 1307 Hijra [= 1891/92], and this is doubtless the date of construction. (The instrument has not previously been correctly dated.) Thereafter is a statement that the leap years in the table are marked in red.

Part XIVc

A monumental astrolabe for the Ayyubid Sultan al-Muʿaẓẓam

To the memory of Professor Aydın Sayılı

DEDICATION,
ACKNOWLEDGEMENTS AND NOTES TO THIS VERSION

It was rare indeed that a scholar in the middle of the 20th century should write the first history of a subject that remains the standard work well into the 21st century. Such was the achievement of Aydın Sayılı (1913-1993) with his book *The Observatory in Islam and its Place in the General History of the Observatory*, (Ankara: Turkish Historical Society, 1960, repr. New York: Arno Press, 1981). Yet that book was based on only part of Sayılı's doctoral dissertation "Institutions of Science and Learning in the Moslem World", submitted to Harvard University in 1941: of this, some 80-odd pages were devoted the observatories, and the other 240-odd pages to madrasas, hospitals and libraries. Alas, these other sections were never published. Nobody has even tried to update Sayılı's work on the observatory, or even sections of it. A brief biography and list of publications, several of which deal with instruments described in Arabic manuscripts, is contained in *Aydın Sayılı Özel Sayısı*, I-III, a special issue of *Erdem* (Ankara: Atatürk Kültür Merkezi), in three parts (9:25-27), Ankara: Türk Tarih Kurumu Basımevi, 1996-1997, vol. 1, pp. 31-57. One of Sayılı's most distinguished students is Sevim Tekeli, author of a series of studies on Islamic scientific texts, including several dealing with instruments, and a most remarkable comparative study of the observational instruments of Taqi 'l-Dīn and Tycho Brahe.

This study first appeared as "The Monumental Syrian Astrolabe in the Maritime Museum, Istanbul", in *Aydın Sayılı Özel Sayısı*, vol. II, pp. 729-735 and 10 pls. I extend my gratitude to the Deniz Müzesi in Istanbul, particularly to Dr. İskandar Pala, during my visits to the museum in 1991 and 1994. On the second occasion, we together carried the astrolabe to the proximity of a window, laid it on the ground, and I was able to take numerous photos. No decent pictures of the front and back are available, and the splendid colour picture used for the cover of the official guide to the Museum shows the rete mounted on the back (compare **Fig. XIIIa-3.2a**). (This is pretty good for any naval museum, and clear proof that the standard astrolabe was never used in navigation.) Those of my pictures reproduced here are sometimes different from the ones used in my first publication on the Istanbul astrolabe, so that the interested reader may find it worthwhile to consult both.

Ideally, this astrolabe should have been published together with the two monumental astrolabes of ʿAbd al-Karīm al-Miṣrī preserved in the British Museum (complete) and the Museum of the History of Science at Oxford (with a replacement rete), which I have catalogued but am not ready to publish yet.

In my original text, I suggested that the most distinctive feature of the design of the rete on this astrolabe—the short equinoctial bar near the top of the vertical axis—might have been copied from a French astrolabe. Since it took several years for the Sayılı memorial volumes to be published and since I never saw the proofs of the article, I was unable to change this before publication. I corrected the assertion in my 1991 book *Ciphers of the Monks* (p. 395), for, as I suggest again below, it may be that the distinctive design of medieval French astrolabes

was copied from the kind of design attested on this Syrian astrolabe. Part of this tale, and more, is recorded with some glee in Sezgin & Neubauer, *Wissenschaft und Technik im Islam*, II: Astronomie, p. 101, unfortunately repeated in *Mainz 2004 Exhibition Catalogue*, p. 455, and inevitably without any illustrations of any relevant French astrolabes, such as I now include here.

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0 Introductory remarks

In the Maritime Museum (Deniz Müzesi) in Istanbul, there hangs an enormous brass astrolabe damascened in silver.[1] With a diameter of 56 cm and thickness of 1.1 cm, it is the largest surviving Islamic astrolabe from the period ending in 1600. But it has not yet received the attention that it deserves; indeed, it has been unlucky on several counts. First, it was, until recently, known in the modern literature only by a couple of passing references.[2] Second, no photographs of publishable quality are available. And third, the astrolabe was supposed to have been exhibited at the splendid exhibition on Syria held at the Institut du Monde Arabe in Paris during 1993-1994 (see **XIVb**); however, for technical reasons, some related to the imagined security needs of a military establishment (the Museum belongs to the Turkish Navy), this turned out to be not possible.

Syria was the scene of intense astronomical activity during the Ayyubid and Mamluk periods and the Syrian astronomical instruments that were exhibited in Paris included some of the most remarkable ever made by Muslim astronomers. A description of the Maritime Museum astrolabe in French was included in the catalogue, but without illustrations,[3] and the purpose of this study is to bring the instrument to the attention of a wider audience.

The provenance of this instrument is not known. Its rather simple rete design bears some resemblance to that of the astrolabe featured in the miniature from the *Shāhinshāhnāme* in MS Istanbul University Library F-1404, fol. 57r, showing the astronomer Taqi ʻl-Dīn with his staff at the Istanbul Observatory (see **Fig. X-1.1**).[4] But the rete of Taqi ʻl-Dīn's astrolabe does not exhibit the most distinguishing feature of the rete on this piece (see below). And in addition, the instrument depicted in the miniature, held at arm's length in the hand of Taqi ʻl-Dīn or his assistant, is smaller. It is not possible for one man to hold up the Maritime Museum astrolabe; in fact, it takes two men to even move it.

The astrolabe was made in Damascus in 619 H [= 1222/23] for the Ayyubid Sultan al-Muʿaẓẓam Sharaf al-Dunyā wa-'l-Dīn ʿĪsā ibn Abī Bakr, who from 597 H [= 1200/01] to 615 H [= 1218/19] was Governor of Damascus and thereafter until 624 H [= 1227] was ruler of the entire Ayyubid realm. The name of the maker indicates that his family came originally from Baalbek and the epithet al-Najjār that he was a craftsman, not necessarily a carpenter (see **XIIIa-11** and **XIVb-8.2**); he is previously unknown to the modern literature. The positions of the markings were calculated by ʿAbd al-Raḥmān ibn Abī Bakr al-Muqawwim al-Tabrīzī, likewise new to the literature. The appellation *al-muqawwim* probably refers to his occupation as a compiler of ephemerides (*taqwīm*, pl. *taqāwīm*, from the verb *qawwama*),[5] but it is not attested elsewhere. The astrolabe was inlaid with silver by al-Sirāj al-Dimashqī, perhaps

[1] Inventory no. 264. The instrument has been assigned the number 4050 in the International Instrument Checklist.

[2] Maddison, "Locks" (1985), p. 153, n. 30, and also *idem*, "The Barber's Astrolabe" (1992), p. 352.

[3] *Paris IMA 1993-94 Exhibition Catalogue*, p. 480. On the other instruments featured there see **XIVb**.

[4] On this miniature, see Sayılı, *The Observatory in Islam*, pl. 6, and also pp. 294-295.

[5] See the EI_2 article "Taḳwīm" by Michael Hofelich, and also King, "Lunar Crescent Visibility Predictions in Medieval Islamic Ephemerides", p. 235.

identical with the muezzin and astrolabist known by three surviving instruments, each far more modest than this one.[6]

1 Description of the astrolabe

The throne, which stands 4.7 cm above the rim, bears no markings. The scale of the rim is divided and labeled for each 5°, with subdivisions for each 1°, as altitude scales in the upper quadrants and as zenith-distance scales in the lower ones (unusual). The throne, the rim and the mater are cast as one piece and there are no markings on the mater besides a peg at the bottom.

The rete is distinguished by a short equinoctial bar inside the southern (upper) ecliptic in addition to a much longer one below the northern ecliptic. The former bar is attached to the ecliptic by two rectilinear supports, the latter by three, on the middle one of which there is a semi-circular handle perpendicular to the rete. The horizontal bar is rectilinear and the vertical bar extends from the substantial central disc to the middle of the upper equinoctial bar. The scale of the ecliptic is divided for each 1°. The star-pointers are elegantly executed in a most unusual way: they are basically triangular in shape, with semi-circular indents at the middle of each side. The stars are named in *kūfī* and in most cases have been repeated (with minor variants) in an Ottoman hand. The 20 stars represented are the following standard ones (arranged in increasing right ascension, starting at the vernal equinox):

raʾs al-ghūl	*qalb al-asad*	*al-nasr al-wāqiʿ*
ʿayn al-thawr	———	*al-nasr al-ṭāʾir*
al-ʿayyūq	*al-simāk al-aʿzal*	*al-ridf*
rijl al-jawzāʾ	*al-simāk al-rāmiḥ*	*mankib al-faras*
yad al-jawzāʾ	*munīr al-fakka*	*kaff al-khaḍīb*
———	*qalb al-ʿaqrab*	*dhanab qayṭūs*
al-shiʿrā al-yamāniya	*raʾs al-ḥawwāʾ*	
al-shiʿrā al-shaʾāmiya	———	

[6] These are:

#4160 / §1.5.2a—dated 623 H [= 1225/26]—Hyderabad, Salar Jung Library, inv. no. 113/2 xxxv—published by Sreeramula R. Sarma in *Hyderabad SJL Catalogue*, pp. 23-24 (no. 6), with an illustration of the back on pl. 12.

#3765 / §1.2.5b—dated 626 H [= 1228/29]—Rampur, Raza Library, inv. no. 1832 D—Gunther, *Astrolabes*, I, p. 247 (no. 102A); published by Padmakara Dube in "Rampur Astrolabes", pp. 1-5, and pls. I-III; and in greater detail by Sreeramula R. Sarma in *Rampur RL Catalogue*, pp. 25-33 (no. 1). The signature is shown in **Fig. 4j**.

#1042 / §1.5.5c—dated 628 H [= 1230/31]—Greenwich, National Maritime Museum, inv. no. A17-36.17—illustrated in *Greenwich Astrolabe Booklet*, p. 45; a full description by François Charette is to appear in *Greenwich NMM Catalogue*. The signature is shown in **Fig. 4k**.

Mayer, *Islamic Astrolabists*, p. 83, mentions the last two of these under al-Sarrāj. The name can be read al-Sarrāj or al-Sirāj, but the latter seems more likely here, being short for Sirāj al-Dīn. On the other hand, the 14th-century Aleppo instrument specialist must be Ibn al-Sarrāj. On the same name, it has been possible to show that the Sirāj al-Dunyā wa-'l-Dīn who included a world-map in his treatise on folk astronomy compiled *ca*. 1210 (see King, *Mecca-Centred World-Maps*, pp. 90-91, is none other than the celebrated Ḥanafī legal scholar Sirāj al-Dīn al-Sajāwandī: see my forthcoming contribution to the *Festschrift* for Professor Hossam Elkhadem, listed as "al-Sajāwandī's World-Map".

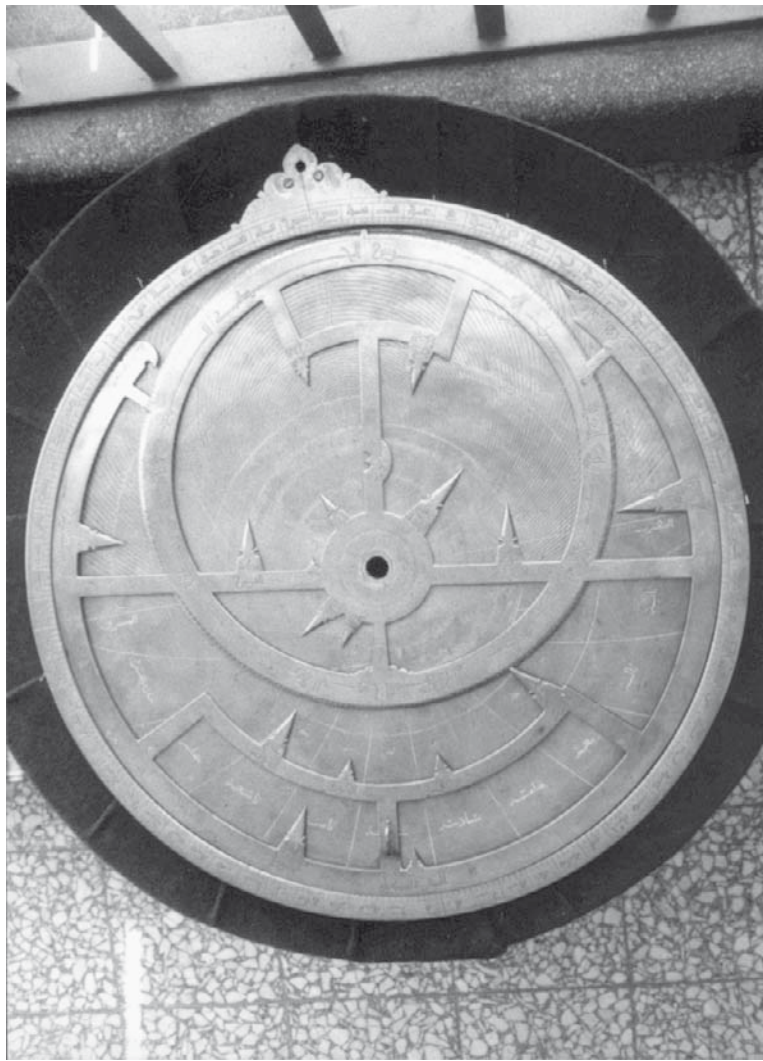



Fig. 1: The front of al-Baʿlabakkī's astrolabe (#4050). [Photos by the author, courtesy of the Maritime Museum, Istanbul.]

There are no construction markings on the back of the rete. The positions of the stars are accurate for the epoch of the instrument,[7] and further investigation is necessary to establish from which star-table they might have been taken.

The one surviving original plate out of an original three (or perhaps only two) has altitude circles for each 1° of argument and curves for the seasonal hours, all constructed with extreme care and accuracy. The latitudes served are 30° and 35°, the associated lengths of longest

[7] Stautz, *Mathematisch-astronomische Darstellungen auf mittelalterlichen Instrumenten*, pp. 66-67 (SA2) and fig. 3.6b on p. 208. (The graphics show the correspondence with Ptolemaic coordinates adjusted to 1222 with the *Mumtaḥan* value of precession.)

Fig. 2a: The distinctive rete. Compare **Figs. 8a-c** below.

Fig. 2b: The pointer for *raʿs al-ghūl* and *al-ʿayyūq*. Note the additional names in *naskhī* script.

Fig. 2c: The pointer for *al-nasr al-wāqiʿ* above the altitude circles around the zenith of one of the plates.

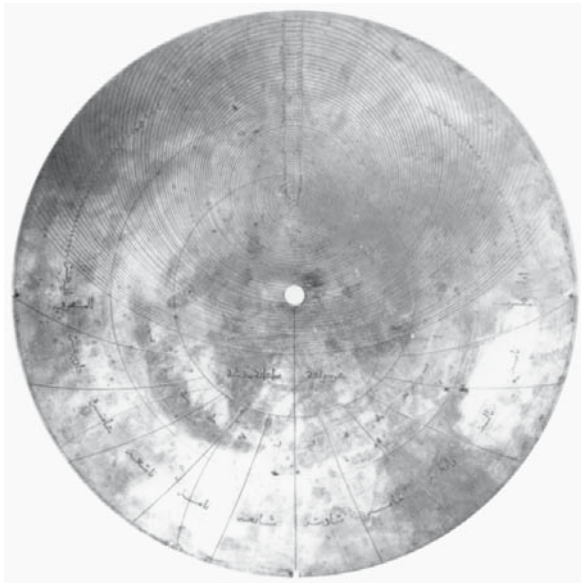



Fig. 3a: The plate for latitude 35°.

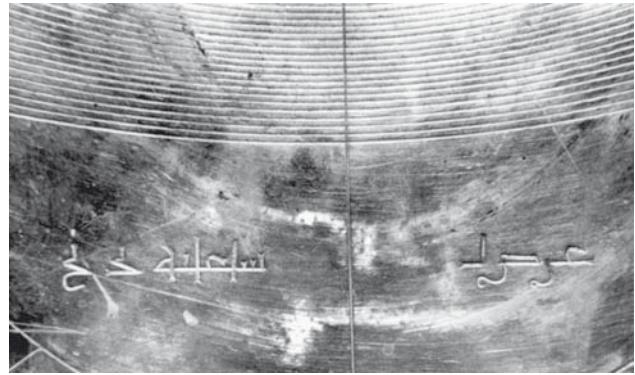



Fig. 3b: The inscription on the plate for latitude 30°.

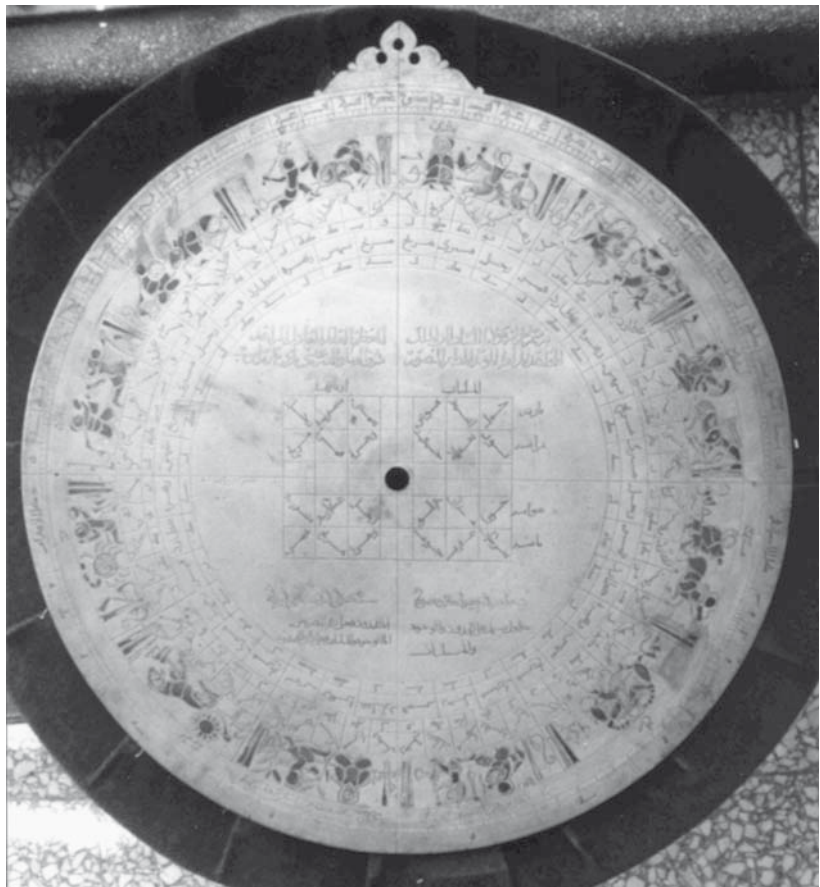
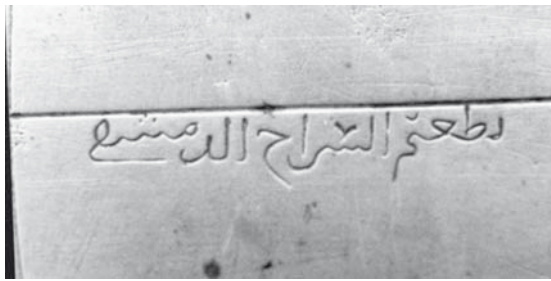
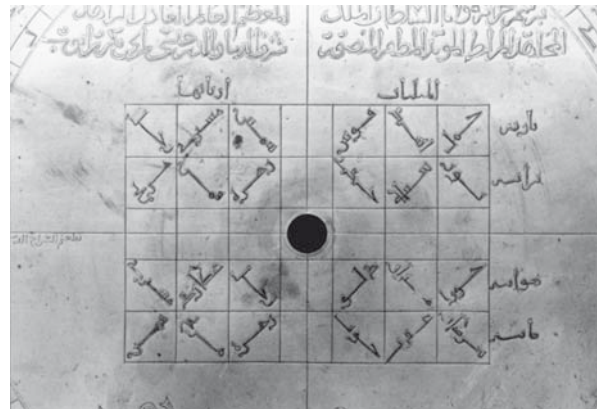



Fig. 4a: The back.

Fig. 4b-i: (b/c) The dedication to the Sultan.
(d/e) The inscription mentioning Damascus as the place of construction and the date.
(f) The signature of al-Baʿlabakkī.
(g) The signature of al-Tabrīzī.

h

i

j

k

Figs. 4h-i: (h) The signature of al-Sirāj.
(i) The astrological data at the middle of the back.

Figs. 4j-k: The signatures of al-Sirāj, the muezzin in Damascus, on two of his three surviving astrolabes, dated 626 H (#3765) and 628 H (#1042). [Courtesy of Professor Sreeramula R. Sarma, Aligarh (object in Raza Library, Rampur) (j); courtesy of the National Maritime Museum, Greenwich (k).]

daylight being given as $13;58^h$ and $14;25^h$. The first of these would have been intended for Cairo. There must have been at least one or two other plates which would have served 33° or 33;30° (Damascus) and perhaps Jerusalem and Aleppo. The lengths of longest daylight are based on the Ptolemaic obliquity of 23;51°, rather than any of the more up-to-date values found by Muslim astronomers in the 9th and 10th century. (This is typical of many medieval Islamic astrolabes.) The seasonal hours are numbered both in *abjad* notation and in words. The side for 35° has two unlabelled curves across the curves for the seasonal hours on the left, which serve the beginning and end of the *ʿaṣr* prayer. The other two plates are not original and bear markings for the latitude of Istanbul: see below.

The back bears an altitude scale subdivided for each 0;30° above the horizontal diameter. The lower scales are divided for shadows to base 7 and 12 and marked *ẓill al-aqdām* and *ẓill al-aṣābiʿ,* respectively. There is a zodiacal scale running counter-clockwise from the top: for each sign an illustration of the sign and of the appropriate planet that has its domicile therein (Mars for Aries, *etc*.) are superposed on the name of the sign. The images merit the attention of an art historian. Inside are the limits and faces, for Aries, for example:

Jupiter 6 Venus 12 Mercury 20 Mars 25 Saturn 30
Mars 10 Sun 20 Venus 30

Below the horizontal diameter is a table of the triplicities and their lords, organized according to their attributes:

	Triplicities			Lords		
Fiery	Aries	Leo	Sagittarius	Sun	Jupiter	Saturn, *etc*.

The inscriptions (A-E below) are as follows:

برسم خزانة مولانا السلطان الملك المعظم العالم العادل الزاهد المجاهد المرابط المؤيّد المظفّر المنصور شرف الدنيا والدين
عيسى بن أبي بكر بن أيّوب

A: "By order of the treasury of our Lord the Sultan, the King al-Muʿaẓẓam, the just and pious scholar, the fighter in the Holy War, the Warrior, supported (by God), made victorious (by God) (*al-muẓaffar al-manṣūr*) Sharaf al-Dunyā wa-'l-Dīn ʿĪsā ibn Abī Bakr ibn Ayyūb."

عمل بمحروسة دمشق في سنة خيط الهجرية

B_1: "Made (ʿ*umila*) in Damascus, (the city) protected (by God), in the year 619 Hijra [= 1222/23]."

جداول تشتمل على الحدود والوجوه والمثلثات
أما الحدود فعلى المصريين
أما الوجوه والمثلثات فعلى رأي الجمهور

B_2: "(The) tables contain the limits and the faces and the triplicities. The limits are according to the opinion (*zaʿm*) of the Egyptians. The faces and triplicities are according to the opinion of the majority of scholars (*raʾy al-jamhūr*)."

صنعه عبد الرحمن بن سنان البعلبكي النجّار

C: "(This astrolabe was) constructed by (*ṣanaʿahu*) ʿAbd al-Raḥmān ibn Sinān al-Baʿlabakkī al-Najjār."

D: "(The positions of the markings were) calculated by (*ḥāsibuhu*) ʿAbd al-Raḥmān ibn Abī Bakr al-Muqawwim al-Tabrīzī." (See **1**.)

تطعيم السراج الدمشقي

E: "Inlaid by (*taṭʿīm*) al-Sirāj al-Dimashqī." (See **1** and **Fig. 4j**).

حاسبه عبد الرحمن بن أبي بكر المقوّم التبريزي

There is no alidade and it is not clear that there ever was one. Certainly, it would never have been possible for one person to hold the astrolabe in one hand and adjust the alidade with the other!

Later additions:
The star-names are repeated in an Ottoman *nashkī* hand, with the following variations: al-*shiʿrā yamāniya*, *nayyir al-fakka*, *nasr al-wāqiʿ*, *dhanab al-qayṭus*. The names of *yad al-jawzāʾ*, *al-simāk al-rāmiḥ*, *al-ridf* and *dhanab al-jady* are not repeated.

Two additional plates do not bear original markings. One is discoloured and bears altitude circles for each 1° but no seasonal hour curves on one side. The markings are not carefully engraved and purport to be for latitude 41° where the maximum daylight is 15^h. The other side is blank but for a few circles without astronomical significance scraped around the centre. The third plate is better preserved and bears a set of altitude circles for each 1° and curves for the seasonal hours. The underlying latitude is not stated but is [41°]. The other side is lightly engraved with the three base circles and two base diameters. Both replacement plates have cut-outs at the bottom that are smaller than the one on the original plate.

2 Concluding remarks

It would be most interesting if the various contributors to this splendid instrument had given us more details of their contributions. It is probably idle to speculate too much on what was precisely intended by the verbs *ʿamila*, *ṣanaʿa*, and *ḥasaba*, although at least *ṭaʿʿama*, to inlay, seems clear.

One of the most historically significant aspects of this instrument is the short equinoctial bar inside the upper ecliptic. No other contemporaneous Islamic instrument exhibits this first feature; indeed, the only other Islamic astrolabe with such an upper equinoctial bar of this kind known to me is an unsigned 15th(?)-century Maghribi piece (#3643): see **Fig. 5a**.[8] Of course, there are numerous Islamic astrolabes with different kinds of upper equinoctial bars: see, for example, **Fig. XVII-2.1**. Now since the same kind of bar as on al-Baʿlabakkī's rete is very much typical of a substantial subgroup of medieval French astrolabes,[9] this raises the interesting question whether the basic rete design might have been copied from an instrument brought to the Ayyubid realms during the Crusades. Or was it the other way round: a Crusader taking back to France a feature he had seen on a (rare kind of) Islamic astrolabe? Most of these French instruments can be dated to the 14th century, culminating in the productions of Jean Fusoris of Paris *ca*. 1425: see **Fig. 5b**. However, **Fig. 5c** shows an example in a French manuscript apparently dated 1276-77, where an upper bar that does not correspond to the equinoctial circle is used for the same purpose, namely, as a support for star-pointers. **Fig. 5d** shows an actual French astrolabe of the same design probably dating from the 13th century.[11] Whatever the

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[8] On this see *Washington NMAH Catalogue*, pp. 177-179 (no. 3643), and fig. 118.
[9] See Poulle, *Fusoris*, especially pp. 19-26 and pls. I and III, and King, *The Ciphers of the Monks*, p. 395.
[10] See already *ibid*., p. 397, citing *Berlin MGB 1989 Exhibition Catalogue*, pp. 110 and 654 (no. 6/10).
[11] Glasemann, "Zwei französische Astrolabien", esp. pp. 213 and 225-226.

original inspiration behind the upper bar(s) on French astrolabes, the distinctive "flame" shape of the star-pointers on these seems to be influenced by Catalan astrolabes.[12] As far as the star-pointers on al-Baʿlabakkī's astrolabe are concerned, Burkhard Stautz mistakenly stated that they were somewhat reminiscent of (*erinnert etwas an*) the forms on early Islamic astrolabes.[13] Inevitably, this was repeated by Fuat Sezgin (now without the word *etwas*).[14] In fact, they bear no resemblance whatsoever to early Islamic star-pointers (see **XIIIa-b**), and the only rete I know that has similar extended triangular pointers is one illustrated in an 11th-century European manuscript: see **Fig. 5e**.[15] Thus, one should be very careful when stating that this design influenced French astrolabes, and the Paris school will surely be ready to deny this possibility anyway.[16]

This is just one of many Islamic instruments preserved in the museums of Istanbul. The rich collection in Kandilli Observatory has been catalogued by the late Professor Dr. Muammer Dizer[17] and those in other museums by myself (but not yet published). They constitute important historical sources whose importance is only now coming to be appreciated. The Maritime Museum astrolabe should eventually be included in a comparative study of two other royal

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Fig. 5a: The only other Islamic piece with such an upper equinoctial bar known to me is a late unsigned Maghribi piece (#3643). The counterchanged vertical bar within the upper ecliptic is also unusual. I would dismiss any suggestion that this was influenced by a French astrolabe. [Courtesy of the National Museum of American History, Washington, D.C.]

Figs. 5b-e: On the chicken?? (see **Fig. 2a**) and its various eggs??

(b) The rete of an astrolabe (#193) from the workshop of Jean Fusoris, Paris *ca*. 1400. The distinctive upper equinoctial frame is clearly taken from an astrolabe rete such as the Damascus piece of al-Baʿlabakkī. Or is it? Certainly the star-pointers are in a European tradition, apparently first used in Catalonia. Here the upper equinoctial bar works rather harshly. On *earlier* French astrolabes a more elegant kind of frame, unrelated to the equinoctial circle, was a stylistic feature of the design: see **Figs. 5c-d**. [Photo courtesy of the late Roderick Webster, instruments now in the Adler Planetarium, Chicago, Ill.]

(c) An illustration of a French astrolabe in a manuscript apparently dated 1276-77. The upper frame, here in two parts, serves to support star-pointers that would otherwise be too long for comfort. [In MS Berlin Deutsche Staatsbibliothek lat. fol. 601, fol. 67v or 68r, taken from *Berlin 1989 Exhibition Catalogue*, pp. 110 and 655 (no. 6/10).]

(d) A French astrolabe with a rete of the same design (#4524), down to the minuscule spherical globules at the end of the star-pointers. [Photo by Reinhard Glasemann, courtesy of the Historisches Museum, Frankfurt am Main.]

(e) Long triangular star-pointers on an astrolabe rete illustrated in an 11th-century manuscript of uncertain provenance. No early Islamic astrolabe has pointers like this. [From MS Vatican BA reg. lat. 598, fol. 120r, courtesy of the Biblioteca Apostolica Vaticana.]

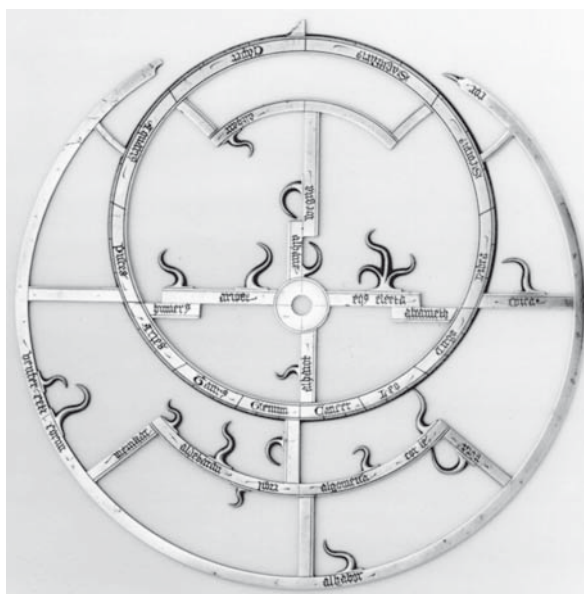
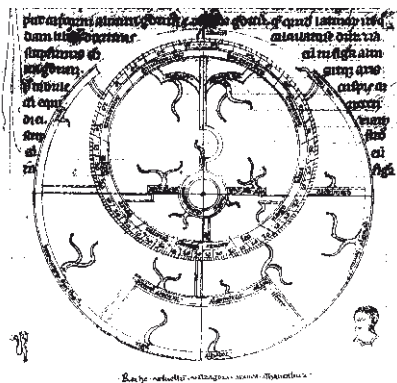
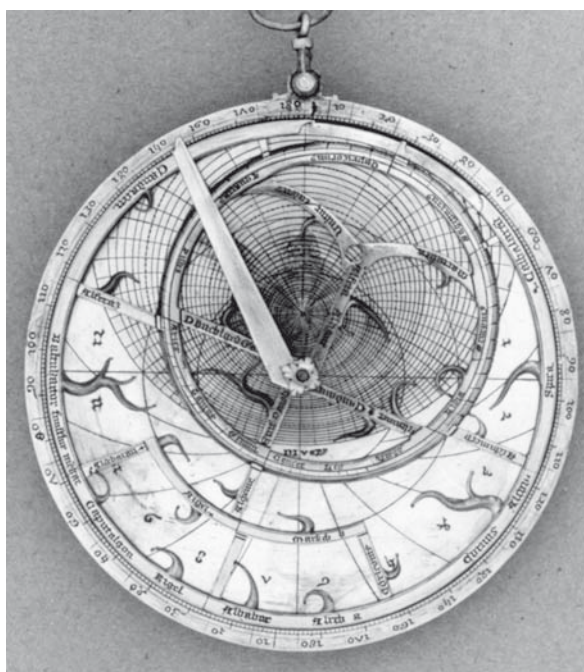
[12] The evidence is #416, a Catalan astrolabe from *ca*. 1300, preserved in the National Maritime Museum at Greenwich (inv. no. A21/NA36-21c). On this piece, see King, "The Oldest European Astrolabe", fig. 14, and *Greenwich Catalogue* (forthcoming). The distinctive V- or Y-shaped frames on medieval (14th-century) English astrolabes is also found on this earlier Catalan astrolabe.

[13] Stautz, *Untersuchungen*, p. 67. Stautz's doctoral thesis advisor missed this error.

[14] Sezgin & Neubauer, *Wissenschaft und Technik im Islam*, II, p. .

[15] See already Bergmann, *Innovationen im Quadrivium*, pp. 46, 101 and 104, and King, *The Ciphers of the Monks*, pp. 406-407.

[16] On astrolabes in medieval France see now King, *The Ciphers of the Monks*, pp. 391-419.

[17] See already *Kandilli Instrument Handbook*.

a b c d e

astrolabes made by ʿAbd al-Karīm al-Miṣrī, now in London,[18] and Oxford,[19] respectively. Both were made in Damascus in the early 13th century for the ruling sultan and both are large, albeit with diameters of *ca*. 30 cm considerably smaller than the piece we have described. Alas, only the former is complete; the latter has a replacement rete by an Iranian craftsman (**XIVd-2**). The zoomorphic rete on the former, however, is one of the most beautiful pieces of metalwork ever made in the Middle Ages.[20]

These instruments stem from a scientific tradition that by the 9th century, as Aydın Sayılı established several decades ago and more recent research has confirmed, was well underway to achieving what one modern historian of science, Kristiaan P. Moesgaard, has called "a level of institutional organization, in observational practice and in theoretical outlook, that would not be equalled in Europe until the sixteenth century."[21] The astrolabe in the Maritime Museum is but one more example of the sophistication of that tradition.

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[18] #104 / §1.5.4b—London, British Museum, inv. no. 55 7-9 1—see Gunther, *Astrolabes*, I, pp. 236-237 (no. 104). On the problem of the inscription see Mayer, *Islamic Astrolabists*, p. 30.

[19] #7 (rete and plates) / §1.4.13b and #103 (mater and plates) / §1.5.4a—Oxford, Museum of the History of Science, inv. no. ICC 103—see Gunther, *Astrolabes*, I, p. 121 (no. 7) and 233-236 (no. 103); Mayer, *Islamic Astrolabists*, p. 30; and on the rete **XIVd-2**.

[20] See the description by an art historian, Michael J. Rogers, in *Washington NGA 1992 Exhibition Catalogue*, pp. 215-216.

[21] In Grattan-Guinness, ed., *Encyclopaedia of the History of Mathematics*, I, p. 246, citing Professor Sayılı's monumental work on the observatory in Islam.

Part XIVd

An astrolabe for the Sultan Ulugh Beg

To S. M. Razaullah Ansari

DEDICATION AND NOTES TO THIS VERSION

I am happy to dedicate this study to my good friend and colleague, Professor S. M. Razaullah Ansari of Aligarh Muslim University. He had made major contributions to our understanding of Islamic astronomy in Muslim India, and has been personally responsible for bringing together interested scholars at congresses and colloquia not only inside India but also all over the world. His activities in numerous organizations, such as his presidencies of the Commission for History of Astronomy in the International Astronomical Union, and of the Commission for Science and Technology in Islamic Civilisation in the International Union for History and Philosophy of Science, have assured him a leading role in the formulation of policy and in our field. This notwithstanding, he has also published widely on astronomy in Muslim India.

Our paths have crossed many times over the years, not least as a result of his almost annual research visits to Frankfurt and my penchant for visiting India under any excuse. Our friendship began in Aleppo in 1975, and was cemented by my visit to Aligarh in 1978. Out of several dozen papers that he has published and numerous books and conference proceedings that he has edited, I mention here only three that deal with instruments:

- ❖ "A Comparative Study of Astronomical Instruments of Jai Singh and the West-Central Asian School of Astronomy" (co-author with S. A. Khan Ghori), in *Proceedings of the Indo-Soviet Seminar on Scientific and Technical Exchanges between India and Soviet Central Asia in the Medieval Period*, B. V. Subbarayappa, ed., New Delhi, 1985, pp. 73-77.
- ❖ "Two Treatises on Astronomical Instruments by ʿAbd al-Munʿim al-ʿĀmilī and Qāsim ʿAlī al-Qāyinī" (co-author with S. A. Khan Ghori), *History of Oriental Astronomy—Proceedings of an International Astronomical Colloquium No. 91, New Delhi, India, 13-16 November, 1985*, G. Swaru, A. K. Bag and K. Shukla, eds., Cambridge, *etc.*: Cambridge University Press, 1987, pp. 215-225.
- ❖ "Two Mughal Celestial Globes" (co-author with S. R. Sarma and A. G. Kulkarni), *Indian Journal of History of Science* 28:1 (1993), pp. 55-65.

This study has not been published previously. It sort of fell together out of the descriptions of Iranian astrolabes before 1500 in my catalogue. Raza Ansari likes Ulugh Beg and delivered a paper "Indian *Zīj* Literature and its Indebtedness to the *Zīj-i Ulugh Beg*", at the conference on the occasion of the 600th anniversary of the birth of Ulugh Beg, held at Farghana in 1994. Nevertheless he has established that his favourite *Zīj-i Muḥammad Shāhī* of Jai Singh is not entirely based on Ulugh Beg's *Zīj-i Sulṭānī*. I hope that he will take pleasure in this account of an astrolabe that (I hope) was made for Ulugh Beg.

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0 Introductory remarks

The astronomical instruments of the Islamic Middle Ages—mainly globes, astrolabes, quadrants and sundials—are an important source for the history of science as well as for the study of Islamic brassware and Islamic art. Yet, the majority of even the most important historical examples are still unpublished. What we know about these instruments has been until recently a matter of chance. Close study of these instruments and investigation of their historical, astronomical and geographical aspects, as well as of their artistic features, can often yield surprises.

In 1990, during routine investigations of the astronomical instruments in Copenhagen, I was able to ascertain that one astrolabe preserved there can be safely associated with Ulugh Beg. Once this was established, it was possible to identify the maker of an unsigned piece in Oxford, a solitary rete, as having been dedicated to Ulugh Beg's father, the Timurid sultan Shāhrukh.

Whilst the monumental sextant erected by Ulugh Beg and his colleagues survives to this day, as well as descriptions of other instruments at the Samarqand Observatory, not one portable instrument from that milieu was previously known to have survived. We can safely assume, however, that there were globes, astrolabes, quadrants and sundials galore in Samarqand in the early 15th century. For example, the astrolabes of the later Lahore school owe their original inspiration to the Samarqand school (**XIVf**). Here, then is the first known portable instrument from Ulugh Beg's scientific circle. It would not surprise me if other such instruments were preserved in unstudied private collections in Uzbekistan.[1]

The instrument bears the signature of Muḥammad ibn Jaʿfar ibn ʿUmar al-Aṣṭurlābī, who was also called Jalāl, the last but one of a family of instrument-makers—ʿUmar, Jaʿfar, Muḥammad and his son Maḥmūd—who originated and were apparently mainly active in Kirman (the name applies to a small city but also an entire province, east of Shiraz and north of Hurmuz). However, Muḥammad / Jalāl clearly also worked in Central Asia. Muḥammad / Jalāl completed this astrolabe in 830 Hijra [= 1428]. He is surely the same Jalāl al-Asṭurlābī mentioned in one 15th-century astronomical source as the instrument-maker at the Samarqand Observatory.[2] On the form of his name see **XIIIb-1.5**.

It is an elegant piece, the rete being carefully decorated in a contemporaneous fashion, more ornate than the Abbasid astrolabes but less so than the later Safavid astrolabes. The throne bears an inscription that enables us to associate the piece with a ruling prince, whose name has unfortunately been obliterated. But the information on the plates enables us to further associate the piece with two localities in Central Asia and hence identify uniquely the unnamed prince as Ulugh Beg. We notice that the dedication, in *naskhī*, is apparently in a different hand from that of all the other inscriptions, which are in *kūfī*. This raises questions about the authenticity of the former. But when inscriptions are added to an authentic instrument it is usually to increase

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[1] My notes indicate that there is another astrolabe by Jalāl in Tashkent, but I cannot confirm this.

[2] Sayılı, *The Observatory in Islam*, p. 267, citing MS Tehran Masjid-i Shūrā-ye Millī 183, p. 2, of the *Zīj-i Jāmiʿ-i Saʿīdī* by Rukn al-Dīn ibn Sharaf al-Dīn al-Āmulī.

the sale value of the piece—witness the 17th-century astrolabe now preserved in Frankfurt with inscriptions associating it with the 13th-century polymath Naṣīr al-Dīn al-Ṭūsī.[3] These were indeed added to achieve, and, in this case, did actually achieve, a truly astronomical sale-price.

The work of Jalāl represents the culmination of the family tradition. It further represents the missing link between the decorative work of the Ayyubid astrolabists and the later Iranian schools. We safely attribute to Jalāl: two astrolabes (A), two globes (G), an unsigned rete and three plates (R+P) made for the astrolabe of ʿAbd al-Karīm al-Miṣrī now in Oxford; and a signed mater (M) recently auctioned in Paris.[4] In addition, there are a solitary plates (P) in an Ottoman astrolabe in Istanbul and London, both of which I currently think were made by him.[4] Details follow:

Location	Type	No.	Date (H)	Diam. (mm)
Fez DB	A	#2710	796	135/122 (?)
Paris IMA	G	#6061 = S-S 61	813	68
Oxford MHS	R+P	#7 *ad* #103	827	244
Copenhagen DS	A	#3595	830	251
Paris Druout 1992	M	#4305	832	?? (small)
London BM	G	#6062 = S-S 62	834	105
Istanbul TIEM	P	#4151	-	142
London NG	P	#4150	-	175

In this study, I shall concentrate on the Copenhagen astrolabe (**1**) but also describe the (slightly earlier) Oxford rete (**2**) and the Istanbul plate (**3**). The star-positions on the two retes merit a separate investigation; the selection of stars points to a textual source that I have not identified. The London plate is described in the caption to **Figs. XIIIa-4.4.1a-b** (by mistake the description was not included here). The Fez astrolabe (**4**) has not been properly researched yet. The Paris mater (**5**) is less exciting. I have the impression that Jalāl excelled only when creating masterpieces for his sponsors; his other surviving pieces, both earlier and later, are less imposing.

1 The Copenhagen astrolabe, dated 1426/27

The astrolabe belongs to the Museum of Decorative Art in Copenhagen, and is now housed in the Davids Samling (= C. L. David Collection), one of the world's major collections of Islamic art.[5] It bears the inventory nos. 6/1972 (Museum) and D25/1986 (David Collection). It has been assigned the designation #3595 in the International Instrument Checklist. The

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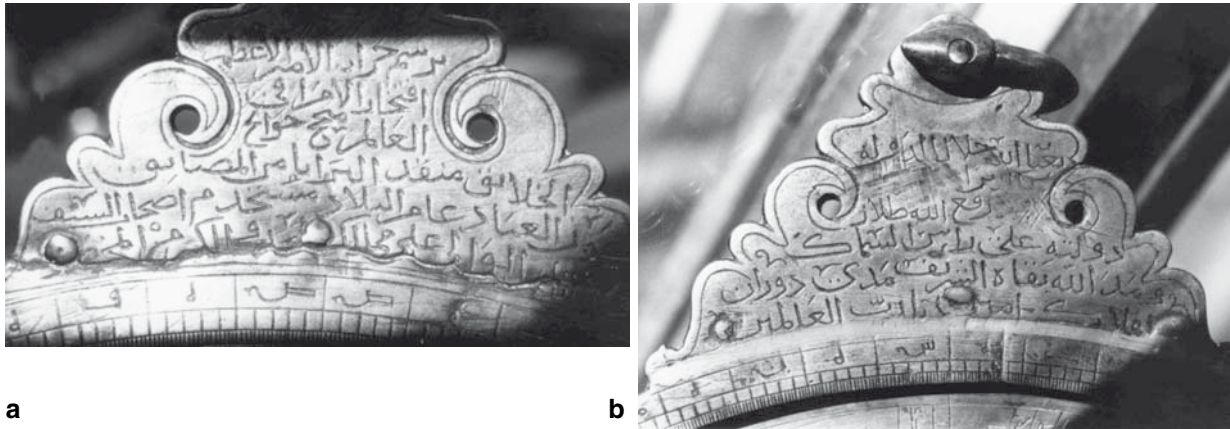
[3] Studied in detail in Schmidl, "Ein Astrolab aus dem 17. Jahrhundert". See also the text to **Figs. XIIIa-3.6a-d**.

[4] Mayer, *Islamic Astrolabists*, p. 68, mentions the London globe; Price *et al*., *Astrolabe Checklist*, p. 60, lists the two astrolabes. See Savage-Smith, *Islamic Globes*, pp. 248-249 (no. 61) and now also *Paris IMA Catalogue*, pp. 80-81 (no. 1) on the Paris globe, and Savage-Smith, *Islamicate Celestial Globes*, p. 249 (no. 62) on the London one. (Neither globe bears a dedication.)

[5] The front is illustrated in *Copenhagen DS Catalogue*, pl. 361 on p. 214, and the rete in King, "Strumentazione", p. 161.

Fig. 1.1: The front of the astrolabe by Jalāl al-Kirmānī (#3595) showing the spectacular rete. [Main photos courtesy of the Davids Samling, Copenhagen. Details by the author, courtesy of the Davids Samling.]

diameter is 251 mm, and the thickness 5 mm. The diameter of the rete is 236 mm. The length and width of the alidade are 240 mm and 16 mm.

The throne was at some stage broken off at its base but is now attached again. It is raised "on a wave" with six lobes and the typical family hole on each side. It is cracked at the join

Figs. 1.2a-b: The inscription on the back of the throne, continuing on the front.

with the mater and has been rivetted back on, apparently very early in its life. The suspensory apparatus is probably contemporary, but it is not original: it originally served an instrument about twice as thick as this one. The rim is brazed onto the back. The scale on the rim is divided with astounding care for 5°/1°/0;15°, and the 5°-intervals are marked without hundreds or tens. The inside of the mater is inscribed (see below), and there is a peg at the bottom to hold the plates. A dedicatory inscription in *naskhī*, which lacks the elegance of the *kūfī* inscriptions on the rest of the instrument, begins on the back and continues on the front: see **Figs. 1.2a-b**. Alas, the name of the person for whom the instrument was made has been deliberately obliterated. The inscription reads:

برسم خزانة الأمير الأعظم | افتخار الأمراء في | العالم مُنجح حوائج | الخلائق منقذ البرايا من المضايق | عون العباد عامر
البلاد مستخدم أصحاب السيف | والقلم الوالي على ممالك المجد والكرم المحظي | بعيانة الله جلال الدولة والدين | ... ...
رفع الله ظلال | دولته على رأس السماك | ومدّ الله بقاه [اقرأ: بقاءه] الشريف مدى دوران | الأفلاك آمين يا ربّ العالمين

This is in rhymed prose, and its complete interpretation may eventually be facilitated by rendering it thus:

برسم خزانة الأمير الأعظم	افتخار الأمراء في العالم
مُنجح حوائج الخلائق	منقذ البرايا من المضايق
عون العباد	عامر البلاد
مستخدم أصحاب السيف والقلم	الوالي على ممالك المجد والكرم
المحظي بعيانة الله جلال الدولة والدين	... ...
رفع الله ظلال دولته على رأس السماك	ومدّ الله بقاءه الشريف مدى دوران الأفلاك
آمين	يا ربّ العالمين

"By order of the Treasury of the Greatest Prince (*al-amīr al-aʿẓam*), pride of (all) the princes in the world, who fulfills (*m-x-ḥ-ḥ*, read: *munjiḥ*?) the needs of the people, who saves mankind from afflictions, the help of (God's) slaves, who makes the cities flourish, patron of the masters of the sword and the pen (*i.e.,* soldiers and scholars),

a

b

Figs. 1.3a-b: Details of the rete.

ruler of the kingdoms of glory and generosity,
beneficiary of the providence of God, splendour of the state and of the religion (of Islam),
A/I/U______ _______ [see below],
may God raise the shadows of his (political) state over the head of Boötes (*al-simāk*)
and may He prolong his noble existence as long as the duration of the revolution of the spheres. Amen, Oh Lord of the Worlds."

The name of the recipient was in two parts separated by a line break; both parts have been obliterated, almost but not quite. Suppose we are dealing with a name of the form *X* ibn *Y*. All that remains of the name *X* is an initial *alif* in the former, signifiying a name beginning in transcription with an "A", "I" or "U". Furthermore, there is an empty space above the second (obliterated) letter so that it could not have been, for example, a *lām* (as in **Ul**ugh). All that remains of the name *Y* is a dot underneath the middle of the name.

Now we are dealing with a prince, rather than a sultan, so Shāhrukh (d. 1447) cannot be intended (see further **2** below). Also we are dealing with a prince with a lot of power, for the inscription borders on heresy (*bidʿa*) with its attributes and achievements of the prince. Perhaps the prince was Ulugh Beg, born in Sultaniyya in 796 H [= 1394], who succeeded his father in 850 H [= 1447] but was murdered by his son near Samarqand in 853 H [= 1449]. His full name was ʿAlāʾ al-Dawla Muḥammad Ṭūrghāy ibn Shāhrukh ibn Tīmūr, and he was known as Ulugh Beg, meaning simply "Great Prince".[6] However, the name in the dedication did not begin with either "ʿAlāʾ ... ", "Muḥammad ... " or, what one would not expect anyway, "Ulugh ... ". Furthermore, in the inscription he is referred to as Jalāl al-Dawla wa-'l-Dīn, and if this is part of his name, as well it might be, Ulugh Beg was called ʿAlāʾ al-Dīn.

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[6] See the splendid volume Wilhelm Barthold, *Ulugh Beg und seine Zeit* (1935), translated from the 1918 Russian version, and the EI_2 summary article "Ulugh Beg" by Beatrice F. Manz. Barthold's book and a collection of early studies on Ulugh Beg's astronomical works and observatory have been reprinted in *IMA*, vols. 54-55 (1998). Two recent short essays "Ulugh Beg as Scientist" and "The Heritage of Ulugh Beg", are published in Kennedy, *Studies*, X-XI. On Ulugh Beg's father see n. 10 below.

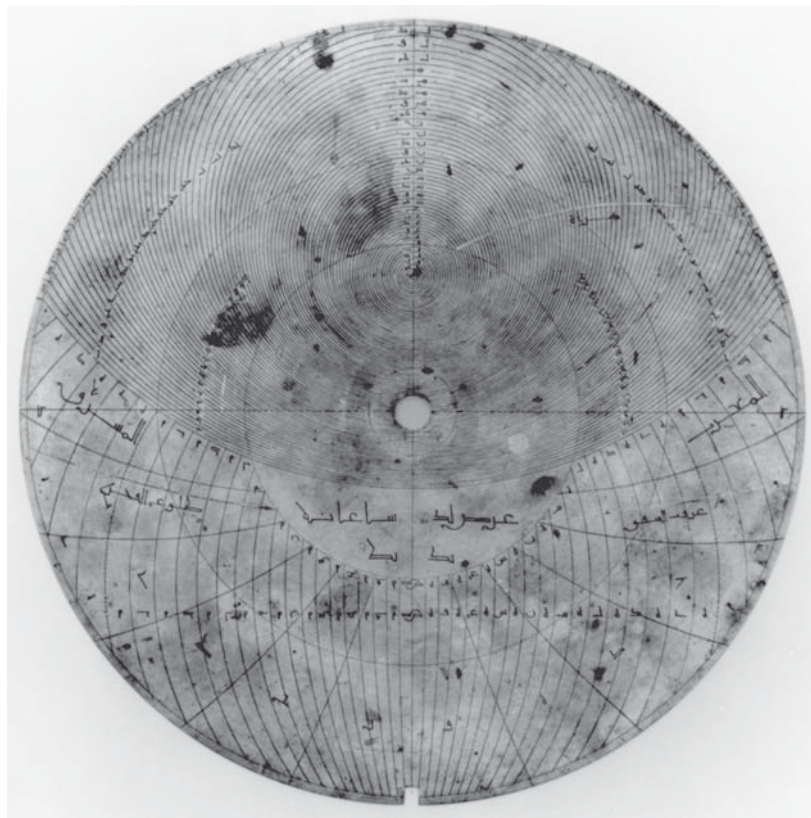
Ulugh Beg had several brothers, of whom at least two had some political influence. One of these was **Ib**rāhīm Sulṭān (this name begins with an *alif*), who ruled in Balkh from 812 to 817 H [= 1414], in Fārs from 818 H [= 1415], and in Luristan in 826 H [= 1423]; he died in 838 H [= 1434/35]. The other was Ghiyāth al-Dīn Baysonghor, who functioned as Shāhrukh's lieutenant from 817 to 836 H [= 1414-32] and died in 876 H [= 1471/72].

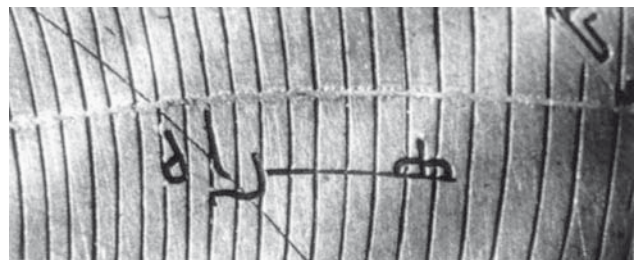
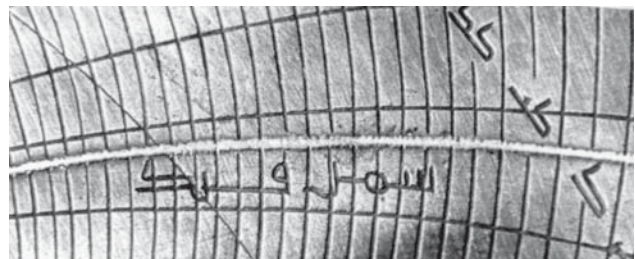
Ulugh Beg still seems to me to be the most likely candidate. It is, after all, possible that his name was engraved on the astrolabe as "**Ib**n Shāhrukh Muḥammad Ṭaraghāy", or even "**Ib**n Shāhrukh Ulugh Beg". Even this, however, does not explain the dot under the second part of the Arabic name.

More to the point, perhaps, Ulugh Beg was passionately interested in astronomy, had founded the Samarqand observatory in 823 H [= 1420], and was the most likely of all of the above in 830 H [= 1428], if not the only one, who would have appreciated receiving an astrolabe and known what to do with it. Add to this the fact that Jalāl actually worked for Ulugh Beg. The clinching evidence, however, is the fact that, as we shall see, two of the plates were specifically intended for use in Samarqand and Herat, and Ulugh Beg oscillated between those two cities; for example, he spent time in Herat in 1422, 1425 and 1434, if not more often.[7] I leave it to others to reconstruct the precise form of the name of the prince (or of anyone else) that was obliterated from the astrolabe.

The rete is a singularly elegant piece. It is similar in design to the Oxford rete but lacks the dedicatory frame, which is fortunate because it would certainly have been broken off anyway (see the Oxford rete!). The equinoctial bar is rectilinear (without counter-changes) and the solstitial axis is decorated with a series of extremely ornate designs, including an endless knot (**Fig. 1.3a**), a frame around the pointer for Vega, represented by a flattened bird (**Fig. 1.3b**), and a frame below the ecliptic that intersects and interacts with a protrusion on the lower equatorial frame. The longer star-pointers are mainly pistel-shaped, the shorter ones tiger claw-shaped. Three pairs of pointers at the top of the rete and on either side below the equinoctial bar form a (_)-shaped ensemble that is typical of later Iranian astrolabes. The latter pairs contain a dummy pointer bearing a handle and the pointer for Regulus. In the interests of symmetry, the lower visual vertical axis has been cunningly twisted to the right. The 29 stars represented are the following:

dhanab al-ḥūt	*maʿlaf* K129	*fakka*
fam al-qayṭus	(= *nathra* in **2**)	*qalb al-ʿaqrab*
ghūl		
dabarān	*fard al-shujāʿ*	*al-ḥawwāʾ*
ʿayyūq	*qafza*	*al-wāqiʿ*
rijl	*qalb al-asad*	*al-ṭāʾir*
yad	*sāq*	*janāḥ*
		dhanab al-jady
shiʿrā al-yamāniya	*ʿanāq*	*mankib*
shaʾāmīya	*simāk al-aʿzal*	*khaḍīb*

[7] Barthold, *Ulugh Beg und seine Zeit*, p. 225.

a

d

b

c

Figs. 1.4a-d: (a) The plate for latitude 34°, serving Herat.
(b-c) The inscriptions on the curves marking the azimuth of the qibla at Herat and Samarqand.
(d) The altitude and azimuth curves around the zenith on the plate for latitude 40°, revealing the accuracy of the markings.

qaʿda	*rāmiḥ*	*dhanab al-qayṭus*
safīna		

The two plates (see **Figs. 1.4a-e**) have altitude circles for each 1° and serve the following latitudes:

1a	32°	14; 8^h	[0]
2a	34	14;19	[0]
2b	36	14;30	[0]
1b	40	14;52	[-2]

The first three lengths of daylight are accurate for the Ptolemaic obliquity 23;51°. The value 14;52^h is accurate for obliquity 23;35°/23;33° but not for 23;51°. The altitude arguments for each 2° are written in two circular arcs midway between the three base circles and again outside the winter solstitial circle, continuing up the meridian to the zenith. The plates for 32° and 34° have azimuth curves for each 5° below the horizon and the plate for 40° has them both above and below the horizon. The azimuth arguments are written along the horizon and again horizontally across the plates (compare **Fig. 2.2a** below). These three plates also have curves for twilight at 19° below the horizon for evening and 17° for morning.[8] The plate for latitude 36° has neither azimuth nor twilight curves, but instead displays the hours since sunset. It would be interesting to know what Jalāl intended for latitudes 32° and 36°. Perhaps he had Rayy in mind for the latter, although it also serves the middle of the 4th climate.

The plates for latitudes 34° and 40° (see **Figs. 1.4a** for the former) also have a curve above the horizon inlaid in silver for the *ʿaṣr* (unlabelled on the former), but the most important feature on these two plates is that they have similar inlaid curves for the azimuths of the qibla at Herat and Samarqand, respectively (labelled only with the names of these two cities)—see **Figs. 1.4b-c**.[9] The azimuths are *ca*. 50° and *ca*. 51;15° measured from the meridian. In the gazetteers of Jalāl's grandfather and father, apparently based on a rather hopelessly-computed table associated with a 13th-century authority named Naṣīr al-Dīn al-Shīrāzī,[10] the relevant data are:

Mecca	L: 77;10°	ϕ: 21;40°	q: -
Herat	94;20°	34;30°	53;50°
Samarqand	98;0°	40;0°	49;0°

The values used by some mid-15th-century scholars in the compilation of the monumental Timurid geographical table that I have labeled TMR are as follows (errors in the minutes for q are given in square brackets):[11]

Mecca	L: 77;10°	ϕ: 21;40°	q: -

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[8] On twilight in Islamic astronomy see my article "Shafaḳ" in EI_2. On twilight parameters in Islamic astronomy see **II**, *passim*, especially **4.10** on the different parameters used in the Cairo corpus of tables for timekeeping. No parameters for twilight appear to be mentioned in the introduction to the astronomical handbooks (*zīj*es) of al-Kāshī or Ulugh Beg, both produced in Samarqand (see Kennedy, "Spherical Astronomy in al-Kāshī's *Khāqānī Zīj*", and Sédillot-*fils*, *Prolégomènes*).

[9] Illustrated already in King, *Mecca-Centred World-Maps*, p. 108.

[10] *Ibid*., pp. 75-76, and editions of the tables on pp. 587-595

[11] *Ibid*., pp. 149-168 and 468-469.

Herat	94;20°	34;30°	54;5° [0]
Samarqand	99;16°	39;37°	52;54° [+1]

I have not investigated further the qibla values used on the plates, given that we do not know the geographical coordinates underlying them. More important is the fact that the additional markings on these two plates confirm that the instrument was made for a prince based in Samarqand who made frequent trips to Herat.

The inside of the mater (**Fig. 1.5**) bears a particularly elegant set of horizons with four sets of half-horizons each fitted with a double declination scale marked in 3°/1° to 24°, although the scales terminate before 24° and it is clear (see below) that an obliquity of 23;30° (as used by contemporary astronomers) was accepted. The latitudes served are:

10°	14	18	...	62
11	15	19	...	63
12	16	20	...	64
13	17	21	...	65

and there are also additional half-horizons for latitudes:

66;30° (= 90° - 23;30°), where the “day” is 24^h and six signs rise simultaneously and the other six gradually (*ufq ʿarḍ sw l al-yawm fīhi kd / yaṭlaʿ sitta burūj ʿala ʾl-dufʿa wa-sitta ʿala ʾl-tadrīj*);

72°, where the “day” is 72^d and Pisces rises before Aquarius in reverse (*ufq ʿarḍ ʿb al-yawm fīhi ʿb / yaṭlaʿ al-ḥūt qabl al-dalw maʿkūs^{an}*);

78°, where the “day” is 114^d and where Aries rises before Pisces in reverse (*ufq ʿarḍ ʿḥ al-yawm fīhi qyd / yaṭlaʿ al-ḥamal qabl al-ḥūt maʿkūs^{an}*);

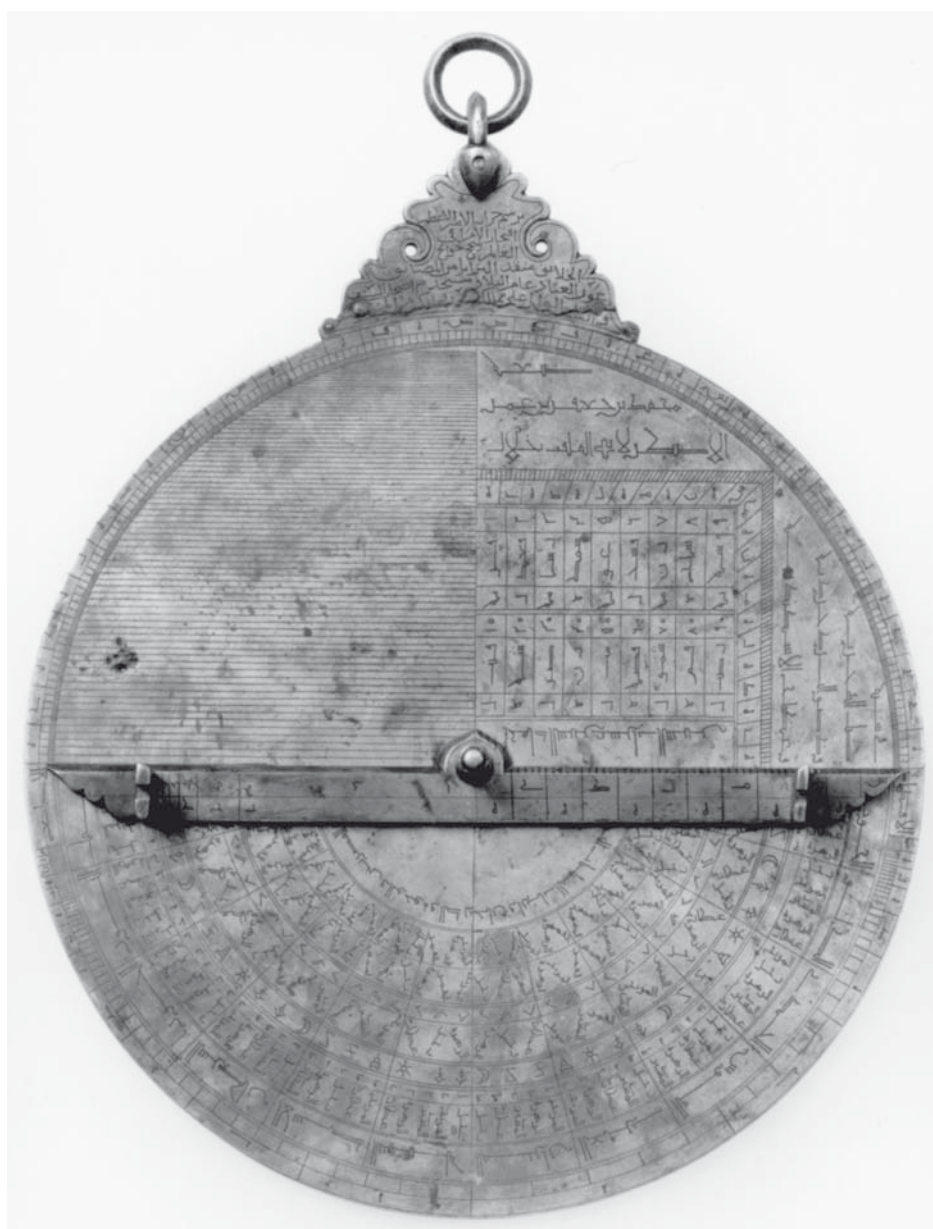
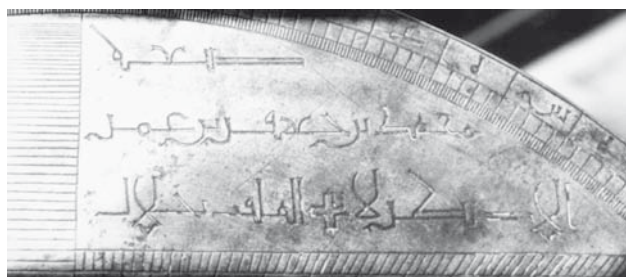
84°, where the “day” is 146^d and where Taurus rises before Aries in reverse (*ufq ʿarḍ fd al-yawm fīhi qmw / yaṭlaʿ al-thawr qabl al-ḥamal maʿkūs^{an}*); and

90°, where the year is one “day” and one “night” (*ufq ṣ takūn sana fīhi yawm^{an} wa-layl^{an}*).

The back of the throne bears the first half of the inscription discussed above. On the upper half of the back (**Fig. 1.6a**), there are two altitude scales and a sine quadrant with horizontal parallels for each 1° up to 80° (damaged on the lower left), and a shadow square (base 60) enclosing an unlabelled table of the *faḍl al-dawr*, which is the excess in equatorial degrees of the solar year over 365 days.[12] The inscription reads simply: “Single years and tens of years” (*āḥād al-sinīn wa-ʿasharāt al-sinīn*) and the number of degrees is given in *abjad* notation for each of the years 1-9 and the tens 10-90, these arguments being written in Hindu-Arabic numerals (unusual). Significant values are:

1: 87;15° 10: 112;30° 90: 292;30°

[12] See further Kennedy, “*Zīj* Survey”, p. 144b and 147. On the way to use this quantity on a celestial globe to find the times of successive “world-years”, that is, at what times of the day the sun will pass the vernal equinox year by year, see Kennedy, “Al-Ṣūfī on the Celestial Globe”, p. 63.

Fig. 1.5: The mater, engraved with a set of horizons, including several for latitudes above the Arctic Circle.

Figs. 1.6a-b: The back and a detail of the signature.

a

b

Figs. 1.7a-b: The alidade and pin.

→

Fig. 2.1b: The dedication on the splendid astrolabe dedicated to Shāh ʿAbbās II (#18), made by Muḥammad Muqīm al-Yazdī in 1057 H [= 1647/48]. [From Gunther, *Astrolabes*, I, pl. XXX opp. p. 132; object in the Museum for the History of Science, Oxford.]

from which it appears that the excess for one year is simply 87;15° with no extra sexagesimal digits. This is the value derived by the celebrated Egyptian astronomer Ibn Yūnus *ca.* 1000 and used by Naṣīr al-Dīn al-Ṭūsī (*ca.* 1250) and al-Kāshī (*ca.* 1420).[13] A different value was used in the *Sulṭānī Zīj* of Ulugh Beg, which was completed only in 842 H [= 1438/39].

Around the shadow square is the inscription (part of which is shown in **Fig. 1.6b**):

صنعه | محمد بن جعفر بن عمر | الاصطرلابي الملقب بجلال ||
في سنة | ضل الهجرية | وذصو اليزدجردية | وغذلج الإسكندرية

"Constructed by Muḥammad ibn Jaʿfar ibn ʿUmar al-Asṭurlābī called Jalāl in the year 830 Hijra and 796 Yazdigird and 1738 Alexander [= 1426-27]."

In the lower half there are shadow-scales for bases 12 and 7 marked *al-aṣābiʿ* and *al-aqdām*, "digits" and "feet", and within these are astrological scales labelled "the limits of the Egyptians and the faces, the *darījān*, the lords of the triplicities by day and by night" (*ḥudūd al-miṣriyyīn wa-'l-wujūh wa-'l-darījān wa-arbāb al-muthallathāt* [*bi-*]*'l-nahār wa-'l-layl*). For each sign

---

[13] Information kindly provided by Dr. Benno van Dalen. Note that al-Ṭūsī in his *Īlkhānī Zīj* simply took over most of Ibn Yūnus' solar, lunar and planetary mean motions, and al-Kāshī's *Khāqānī Zīj* is a reworking of that of al-Ṭūsī.

this information is given in four main groups (separated by a double circular band). In the second planetary symbols are used (for lack of space), and in the others the names of the seven celestial bodies are preferred.

The alidade (**Fig. 1.7a**) is original bears a scale of universal shadows on one half and a uniform scale to 60, marked in 5-unit intervals, on the other. The vanes have a cut-out at the top and a small circular hole just below it. The pin is particularly elegant (see **Fig. 1.7b**).

2 The Oxford rete, dated 1423/24, and plates

> "This addition to a Syrian instrument of A.D. 1227-8 was made by a Persian craftsman two hundred years later." Robert T. Gunther, *Astrolabes of the World* (1932), I, p. 121.
>
> "(The rete) is a replacement, perhaps of Persian origin ... ." Francis R. Maddison, "The Barber's Astrolabe" (1992), p. 350.

Of the two surviving astrolabes by the late-13th-century Damascus craftsman ʿAbd al-Karīm al-Miṣrī, preserved in the British Museum (#104)[14] and the Museum of the History of Science at Oxford (#103),[15] the rete now on the latter is a replacement. Already Gunther noted that the rete was a "Persian" addition and thoughtfully listed it separately (#7).[16] It has not been previously noted that the plates on the Oxford astrolabe are not original either. Both of these magnificent pieces merit a separate study, and our attention here is restricted to the replacement rete on the Oxford piece, which, it has not been previously noted, is clearly by Jalāl. The rete bears a double date 827 H and 793 Y [= 1423/24] engraved on the equinoctial bar, indicating that it was expressly made for the Oxford astrolabe. It has a diameter of 24.4 cm, the mater having a diameter of 28.0 cm.

The attribution of this rete to Jalāl is evident from its similarities to the rete of the Copenhagen piece. This solitary rete once featured the name of the ruling sultan, but his name has been broken off and only the letters *l-ṭ* of *s-l-ṭ-ʾ-n* (= *sulṭān)* remain. With some stretching of the imagination, one could read *s-l-ṭ-ʾ*, and the final (which would be separated from the rest of the word). One would expect al-Sulṭān followed a name. There is certainly room for a short name to have been attached to the now broken bars stemming from the decoration above the centre. Our understanding of this inscription is somewhat facilitated by an almost identical inscription, this time complete, on a later astrolabe dedicated to the Safavid ruler ʿAbbās II (#18) in 1057 H [= 1647/48]: see **Fig. 2.1b**. Here we find unmistakably the letters *l-ṭ-ʾ*, with

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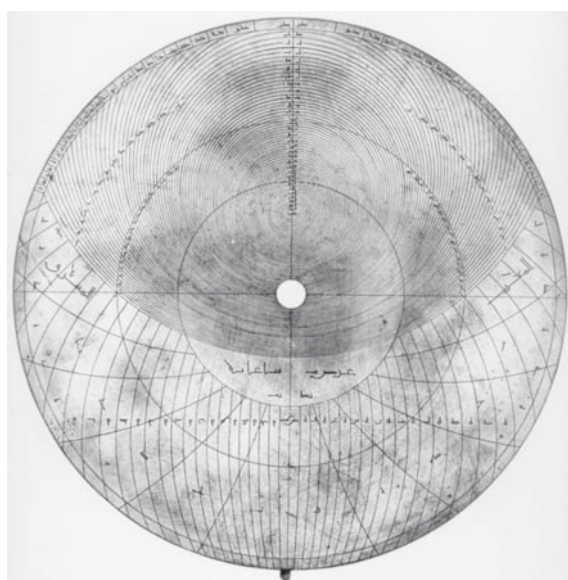
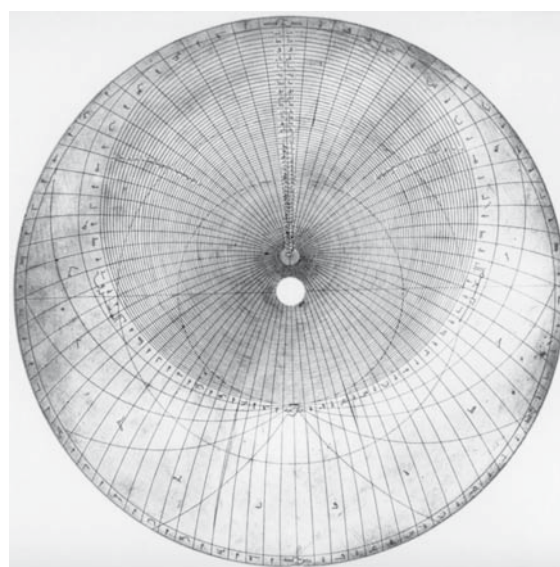
[14] Gunther, *Astrolabes*, I, pp. 236-237 (no. 104); also *Washington LC 1992 Exhibition Catalogue*, pp. 215-216 (no. 112), with important considerations by Michael Rogers on the problematic inscription.

[15] Gunther, *Astrolabes*, I, pp. 233-236 (no. 103).

[16] *Ibid.*, I, p. 121 (no. 7). Francis Maddison, "The Barber's Astrolabe", sees in the Oxford piece the astrolabe inlaid in silver mentioned in the *1001 Nights*. However, 8 out of 13 known Ayyubid and Mamluk astrolabes are inlaid in silver, and the Oxford astrolabe was made in Damascus, not Cairo where the story of the barber with the astrolabe was coined. There is an astrolabe in the Türk ve İslâm Eserler Müzesi (inv. no. 2970, #4036), made in Cairo in the late 13th century (681 H) and bearing inscriptions in Coptic and Arabic, which is inlaid in silver all over. It is a modest 11.4 cm in diameter, and would at least have fitted into a barber's pocket, if there ever was a barber. (The two versions of the barber's tale in the *1001 Nights* mention conjunctions in 653 and 763 H, respectively; the astronomical and astrological information in the tale is corrupt in all of the published editions and translations, but can be partly restored.)

Fig. 2.1a: The rete attributable to Jalāl al-Kirmānī (#7) fitted inside the mater by ʿAbd al-Karīm al-Miṣrī (#103). [From Gunther, *Astrolabes*, pl. LIII opp. p. 234; object in the Museum of the History of Science at Oxford.]

a

b

Figs. 2.2a-b: Two of the plates by Jalāl al-Kirmānī in the Oxford astrolabe (#103). A comparison with those on the Copenhagen piece suffices to establish their maker. They are quite different from those in the London astrolabe of ʿAbd al-Karīm al-Miṣrī (#104). These two serve latitudes 40° and *ca*. 66;30°. [Courtesy of the Museum of the History of Science, Oxford.]

what could be interpreted as an *s* before them and an *n* after them, that is, *sulṭān*. Below this we find a clear dedication to *Shāh ʿAbbās-i thānī*, "Shāh ʿAbbās II".

If the instrument was made in Khurasān or Transoxania (see the Copenhagen piece), the ruler would have been the Timurid sultan Shāhrukh (*reg*. 807-850 H [= 1405-1447] from Samarqand).[17] If it was made in N. W. Iran the ruler would have been Iskandar ibn Yūsuf of the Qara Qoyunlu line, who reigned over Iraq and Azerbeijan from Tabriz (823-841 H [= 1420-38]).[18] The former seems the more likely.

One could imagine that the piece was liberated from the royal treasury in Damascus during the Mongol invasion of 1260 and taken back to Central Asia. Surely, it originally had a richly-decorated zoomorphic rete like that of the London astrolabe. In any case, Jalāl provided it with another rete, which, probably shortly thereafter, also got damaged. No sultan would have been happy with a gift that was not all of one piece, so Jalāl cannot have presented the whole piece to the sultan; the latter must have had it in his possession and simply commissioned Jalāl to complete it. If only these instruments could talk!

Gunther relates that in the late 19th century it was almost acquired by the Prussian Emperor Wilhelm Hohenzollern, who planned to substitute his own name for that of the Mamluk sultan to whom it was originally dedicated, and then take it with him on a planned trip to the so-called Holy Land. Fortunately, it was acquired for Oxford by Lewis Evans (for 175 guineas in 1902) and spared this ultimate indignity.

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[17] See the EI_2 article "Shāhrukh b. Tīmūr" by Beatrice F. Manz.

[18] See de Zambaur, *Manuel*, pp. 257 and 269-270 and Table T, and Bosworth, *Islamic Dynasties,* 2nd edn., pp. 270-271 and 273.

The rete is as elegant as that on the Copenhagen astrolabe, which post-dates it by four years, and, for our purposes, the fact that the main inscription has been broken off is a tragedy. Virtually all of the markers are floral in design, some serving two or three stars; some groups are named on the circumferential bar (these are underlined below). The star (*al-nasr*) *al-wāqiʿ* alone is represented by a figure, a flattened bird. The star *al-shiʿrā* (*al-yamāniya*) is cleverly represented at one side of a gap in the bridge below the equatorial bar, the frame bearing this star being twisted slightly to the right of the solstitial axis, as on the Copenhagen piece. The handle on the left-hand support of the equatorial bar is broken off and only a hole remains. The number of stars represented can only be determined when the pointers have been properly investigated because some flowers have three points but only two names.

The identification of the stars is not without its problems. We are dealing here with a previously-undocumented tradition of astrolabe stars, and some of them have still not been identified. The selection of stars clearly depends on a deliberate attempt to have pointers that are roughly symmetrical with respect to the vertical axis of the rete. Jalāl has used a subgroup of these on the Copenhagen astrolabe (**1**: the numbers are underlined below), and an Ottoman astrolabe in the Iranian tradition (**XIVe**) bears another subset of these stars. Clearly the tradition merits further investigation. The 39 stars are as follows, with the usual references p/q to Paul Kunitzsch's lists of astrolabe stars, and Kr to his lists of Arab star-names.[19]

1	*(al-)naʿamāt* 1/2 (?)	Ø/Ø	one or possibly two of τ υ ζ θ η Ceti (K184)
2	***musalsala***	20/7	β Andromedae
3	***dhanab al-ḥūt***	Ø/Ø	identification uncertain
4	*ṣadr al-qayṭus*	Ø/5+K178	α Cassiopeiae
5	*(al-)ghūl*	9/14	β Persei
6	*fam al-qayṭus*	Ø/Ø	γ Ceti
7	***nahr***	38/12 17?	θ Eridani
8	*(al-)dabarān*	24/18	α Tauri
9	*(al-)ʿayyūq*	10/20	α Aurigae
10	*rijl (al-jawzāʾ)*	37/19	β Orionis
11	*yad (al-jawzāʾ)*	36/22	α Orionis
12	*(al-)shiʿrā al-yamāniya*	39/23	α Canis Maioris
13	*(al-shiʿra 'l-)shaʾāmiya*	40/25	α Canis Minoris
14	***(al-)safīna***	Ø/27	ρ Puppis
15	*(al-)nathra* [M8] (= *al-maʿlaf* in **1**)	Ø/Ø	ε Cancri, *etc*. (?); (M8; see K201, also K156)
16	[*dhanab* ?] (written *d-x-x-ʾ*)	?	?

[19] Namely, "al-Ṣūfī and the Astrolabe Stars", pp. 158-161, and *idem*, *Arabische Sternnamen*, pp. 59-96, as well as *idem*, *Sternnomenklatur der Araber*.

17	*fard al-shujā*ʿ	42/29	α Hydrae
18	*qalb al-asad*	26/30	α Leonis
19	***sāq*** *al-shujā*ʿ	Ø/Ø	?
20	*baṭn al-shujā*ʿ	Ø/Ø	?
21	*rijl (al-dubb)*	Ø/28	μ Ursae Maioris
22	*qafza*	Ø/56	ν ξ (or only ν) Ursae Maioris
23	*(al-simāk al-)a*ʿ*zal*	29/39	α Virginis
24	*dhanab*	?	?
25	*(al-)*ʿ*anāq*	Ø/Ø	ζ Ursae Maioris (K33)
26	*(al-simāk al-)rāmiḥ*	1/41	α Boötis
27	[*(al-munīr min al-)fakka*] (no name — pointer broken)	2/45	α Coronae Borealis
28	*qalb al-*ʿ*aqrab*	30/48	α Scorpionis
29	[*ra*ʾ*s al-ḥawwā*ʾ ?] (no name — pointer broken)	11/51	α Ophiuchi
30	*(al-nasr al-)wāqi*ʿ	4/53	α Lyrae
31	[*al-nasr al-ṭā*ʾ*ir*] (unnamed, only base of pointer remains)	13/54	α Aquilae
32	*janāḥ (al-faras)* (?) (in **XIVe-1** this becomes *janāḥ al-dajāja*)	16/3	γ Pegasi
33	*fam (al-faras)*	19/58	ε Pegasi (see no. 35)
34	*dhanab al-jady*	32/59	δ Capricorni
35	*jaḥfala(t al-faras)*	19/58	ε Pegasi (see no. 33)
36	*mankib (al-faras)*	17/62	β Pegasi
37	*kaff al-khaḍīb*	7/2	β Cassiopeiae
38	*(al-)ḍifda*ʿ *(al-)thānī*	Ø/Ø	β Ceti (K76a=b)
39	*dhanab (al-qayṭūs)*	35/4	ι Ceti

The stars on **1** are, as noted above, a subset of these. I have not identified the star-table from which these stars were taken. Future researchers should keep an eye open for such unusual stars as *al-nathra / al-ma*ʿ*laf* (15), *al-qafza* (22) and *al-ḍifda*ʿ *al-thānī* (38). See also **XIVe-1** for a related set of stars on an astrolabe made for the Ottoman Sultan Bāyazīd.

The plates are clearly also by Jalāl, although this has not been previously noted. They are superbly worked for each 1° of altitude and the lower arguments are also engraved around the outer limb. All but one have azimuth curves below the horizon (A-) for each 5° of argument, with the distinctive arrangement of the arguments across the markings: see **Figs. 2.2a-b**. The latitudes served are:

1a	30°	A-	13;58	[0]
2a	34	A-	14;19	[0]
3a	36	A-	14;30	[0]
2b	40	A-	14;52	[-2]
1b	44	-	15	[-22!]
3b	[*ca.* 66;30]	A-	-	-

The plate for 44° also has the hours since sunset. The latitudes 34° and 40° are clearly for Herat and Samarqand. The latitude 36° can serve any locality in the middle of the 4th climate. With 30°, Jalāl probably intended his family seat in Kirman. Its latitude (accurately 30°18′) was taken as 30;0° already by al-Khwārizmī, which value remained popular for centuries.[20] With 44°, he was clearly thinking of the 6th climate, which would have been better served by 45°, but there the longest day is 15;30°. The lengths of daylight are based on obliquity 23;51°, and some liberties have been taken. For latitude 40°, 14;52h is accurate for obliquity 23;35°.

I do not have any photos of the mater, which Gunther stated is engraved with "a scale of the 'ankabut coordinates' arranged in 4 groups of 15 each". This makes no sense, and it seems that four sets of horizons are meant. Notice that the Copenhagen horizon plate has four groups of 14 each. On the other hand, the mater of the London astrolabe of ʿAbd al-Karīm al-Miṣrī has "ankabut coordinates" for latitude [*ca.* 66;30]°. A quick inspection of the Oxford astrolabe could establish whether these horizons are by ʿAbd al-Karīm al-Miṣrī or by Jalāl.

3 The solitary Istanbul plate

In the Türk ve İslâm Eserleri Müzesi (Museum of Turkish and Islamic Archaeology) in Istanbul there is a late Ottoman astrolabe bearing the name of Yūsuf. The inventory number is T2970 and International Instrument Checklist number is #4151. A spurious plate now fitted in this instrument is clearly the work of Jalāl. The diameter of the plate is 142 mm, so that it would not fit into any of the three astrolabes by Jalāl described here (Copenhagen, Oxford, Fez). The peg at the bottom has broken off.

We may compare not only the astronomical markings and the azimuth arguments written horizontally across the plate but also the distinctive shape of the letter *ghayn* in the word *al-maghrib*.

One side—see **Fig. 3a**—bears a set of altitude circles for each 3° and azimuth circles for each 10° below the horizon. The arguments are labelled in the usual fashion and the inscription reads:

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[20] Kennedy & Kennedy, *Islamic Geographical Coordinates*, pp. 187-188. See also the Addenda at the end of this volume (*ad* **IX**).

a b
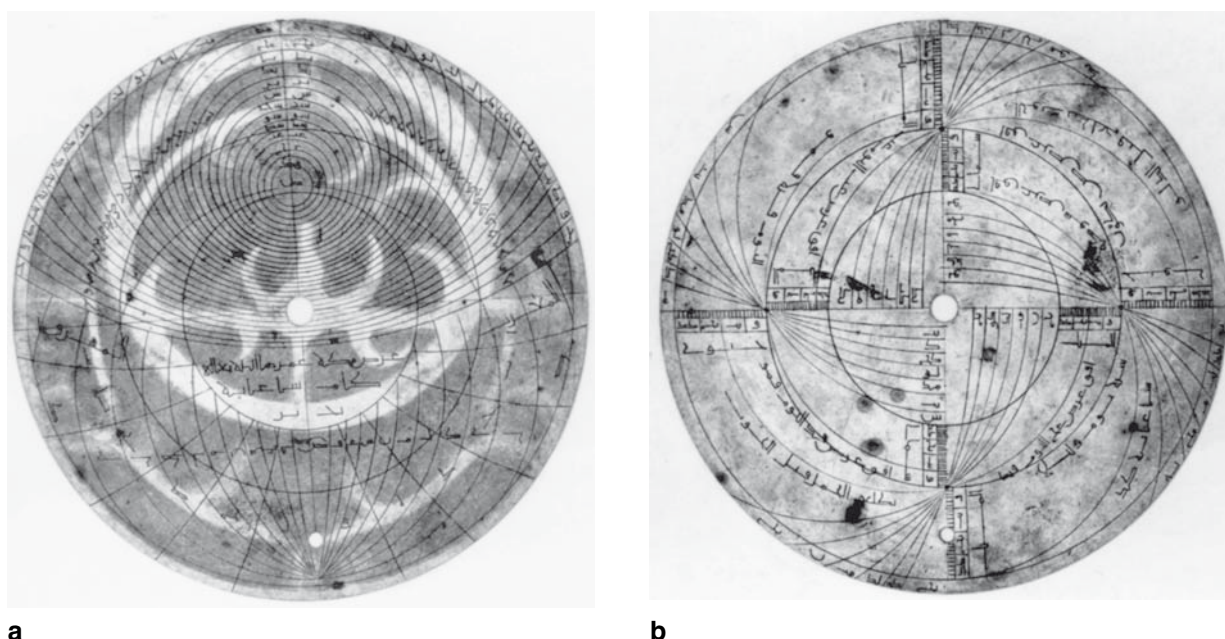
Fig. 3a-b: The two sides of a spurious plate by [Jalāl] found in an Ottoman aṣtrolabe (#4151). The imprint of the new rete is to be seen on the plate for Mecca. [Courtesy of the Türk ve İslâm Eserleri Müzesi, Istanbul.]

"Latitude of Mecca—may God strengthen it (*ʿammaraha ʾllāh*)—
21;40°. Its hours are 13;17."

The "hours" correspond to latitude 21°, not 21;40°, with obliquity 23;35° or 23;30°. On the other side—see **Fig. 3b**—are four sets of half-horizons for latitudes:

12	20	28	36	44	52	60
14	22	30	38	46	54	
16	24	32	40	48	56	
18	26	34	42	50	58	

There are also horizons for latitudes 66;25°, 72°, 78°, 84° and 90° with the same inscriptions as the horizon plate on the Copenhagen piece. The four declination scales are divided 6°/1°-6° to 24°.

4 The Fez astrolabe, dated 1393/94, with some additional markings in Armenian script

An astrolabe now in the Dār al-Baṭḥā, Fez, with inventory no. 764 and International Instrument Checklist no. 2710, is also by Jalāl, probably from the time before he (?left Kirman and?) went to Samarqand. The instrument has a diameter of either 135 mm (notes of Alain Brieux) or 122 mm (Paris Catalogue). Although the date 796 H [= 1393/94] does seem rather early, the reading is clear. It is not in the same class as the Copenhagen astrolabe or the Oxford rete and Istanbul plate, being more typical of the productions of his grandfather and father. Those other pieces

Figs. 4a-b: The front and back of the Fez astrolabe (#2710). There are additional markings by an Armenian craftsman on the scale around the mater and the ecliptic scale. [I have no idea about the source of these photos, which are rather good. I found them whilst sorting out illustrations for this book.]

Figs. 4b.

well reflect what a competent craftsman can achieve when he has a generous sponsor and an intellectual milieu conducive to excellence.

I have not seen this instrument, but in May, 2004, came across photos of the front and back: see **Figs. 4a-b**. One could argue that it has not fared well, neither when it first landed in the Maghrib, nor more recently. Centuries ago, some Maghribi craftsman did not like it, and tried to fix it up according to his own limited local tradition. In 1990, it was to have been featured in the Exhibition on the Maghrib at the Musée du Petit Palais, Paris, but none of the astrolabes from Morocco reached Paris, and the catalogue entries are pathetically inadequate.[21]

On the other hand, there are additional markings of some historical interest. When I first saw the additional numbers on the outer scale and ecliptic scale I thought these might be in *al-qalam al-fāsī*, "chiffres de Fès", which keep showing up in Andalusī, Maghribi and Spanish Latin sources.[22] What would have been more appropriate for an Iranian astrolabe ending up in Fez? Besides, the additional Western Arabic month-names on the back were clearly added by a Maghribi. However, as Roser Comes of Barcelona pointed out to me, the additional numbers are not "chiffres de Fès", but rather lower-case Armenian alphanumerical notation. Where these numbers were added is an open question, and anybody who pursues it should also consider the two Oxford astrolabes of Khafīf discussed in **XIIIb-1.1-2**, which have additional star-names in Armenian.

5 The Paris mater, dated 1428/29

In 1992 a solitary mater by Jalāl (#4305) was auctioned at Drouot in Paris, fitted with a fake rete and set of plates.[23] I do not know the size of this piece, but it is clearly small. The throne is worked *à jour*, and the mater contains a gazetteer in the family tradition. On the upper left of the back there is a wadly-worn trigonometric quadrant with horizontals for each unit, and on the upper right a universal horary quadrant. The lower back bears astrological tables and a typical signature by Jalāl and the date 832 H / 798 Y / 1740 A, which corresponds to 1428/29. No decent photos are available to me. For the fake rete and its quatrefoil decoration see **Fig. XVII-1.9d**.

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[21] *Paris MPP 1990 Exhibition Catalogue*, pp. 240-241 (no. 475), with an illustration of the front.

[22] R. Comes, "Urgell Alphanumerical Notation", and the earlier studies there cited. See, in particular, Colin, "Chiffres de Fès"; Labarta & Barceló, *Números y cifras*; and King, *The Ciphers of the Monks*, p. 314.

[23] A brief description by Dominique Brieux in *Paris Drouot 23.12.1992 Catalogue*, lot 38, notes the importance of the rete and the problems of the other components.

Part XIVe

Two astrolabes for the Ottoman Sultan Bayezit II

To Ekmeleddin İhsanoğlu

DEDICATION,
ACKNOWLEDGEMENTS AND NOTES TO THIS VERSION

This study is dedicated to my good friend and distinguished colleague, Prof. Dr. Ekmeleddin İhsanoğlu, appointed in 2003 Secretary General to The Islamic Conference. We have met many times in many different places over the years, and I would love to meet him one day in Egypt, not least to see the reaction of our Egyptian colleagues to the two of us conversing in Egyptian colloquial. To his great credit, Professor İhsanoğlu has been personally responsible for furthering the history of science in Turkey. He has directed the Research Centre for Islamic History, Art and Culture (IRCICA) since its inception, and provided Istanbul with a centre of scholarship on Islamic civilization second to none. He has also organized a series of conferences bringing together researchers from all over the world. The website www.ircica.org gives an overview of IRCICA's activities and the impressive range of their publications, which indeed cover all of the areas indicated by the name of the Institute. Here I mention only the monumental bio-bibliographical series of six volumes published by Ekmeleddin İhsanoğlu and several of his colleagues on Ottoman astronomy, mathematics and geography, which have raised the subjects to new heights, and which provide reliable reference works for all future researchers:

- *Osmanlı astronomi literatürü tarihi—History of Astronomy Literature during the Ottoman Period*, 2 vols., (Studies and Sources on the History of Science, Series No. 7), 1997.
- *Osmanlı matematik literatürü tarihi—History of Mathematics Literature during the Ottoman Period*, 2 vols., (Studies and Sources on the History of Science, Series No. 8), 1999.
- *Osmanlı coğrafya literatürü tarihi—History of Geographical Literature during the Ottoman Period*, 2 vols., (Studies and Sources on the History of Science, Series No. 9), 2000.

The original version of the present study, entitled "Homage to an Ottoman Sultan: Two Astrolabes Dedicated to Bayezit II", is to appear in the *Festschrift* for Ekmeleddin İhsanoğlu currently in press. In this version I have suppressed the usually indispensable section entitled "What is an astrolabe?", and fixed up numerous cross-references.

For photographs of the two astrolabes discussed here I am grateful to Mme Dominique Brieux of Paris and Sotheby's of London.

TABLE OF CONTENTS

0 Introductory remarks

In this study, I shall discuss two astrolabes dedicated to the Ottoman Sultan Bayezit II (*reg*. 1481-1512).[1] The first, made in 1504/05, is preserved in the Museum of Islamic Art in Cairo. It is not unknown to the literature on the history of Islamic art but has never been properly published. The second, made the following year, came to light in 1998 at an auction of Sotheby's in London and my description of it was published in the auction catalogue. As far as I know, there are no other known astronomical instruments dedicated to an Ottoman sultan, not even in the Topkapı Sarayı Museum.

The history of *early* Ottoman astronomy in general (14th to early 16th century) has not yet been properly researched. It was influenced by the Seljuq Turkish tradition (Anatolia, 13th century), of which very few sources and not a single instrument survive;[2] by the colourful Mamluk tradition (Egypt and Syria, 13th to 15th century),[3] and by the vigorous Ilkhanid and Timurid traditions (Iran and Central Asia, 13th to 15th century).[4] The sources for Ottoman astronomy in general have recently been properly documented for the first time,[5] and the amount of important research for the future is daunting. It would be a good idea if some researchers would dedicate their investigations to the astronomy of the early period.[6]

The interest of Bayezit II in astronomy is well known.[7] He studied mathematics and astronomy with his private teacher, who was none other that Mīram Chelebī, the grandson of Qāḍī Zāde al-Rūmī, director of Ulugh Beg's observatory at Samarqand. Numerous astronomers dedicated their works to him, including treatises on instruments and highly sophisticated tables. He himself commissioned his teacher to prepare a Persian commentary to the astronomical tables of Ulugh Beg. Also, the institutions of court *munajjim*s (astronomer-astrologers) and mosque *muwaqqit*s (timekeepers) were well established in his time.[8]

The early Ottoman tradition of instrument making (14th to 16th century) is represented only by these two presentation pieces for Bayezit II. All other Ottoman astrolabes are later than these two, indeed at least a century later. Out of a total of some 30-odd pieces,[9] none shows any

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[1] Article "Bāyazīd II" by V. J. Parry in *EI*$_2$.

[2] See, for example, Sayılı, *The Observatory in Islam*, pp. 253-255, also **II-14.1-2**.

[3] See King, "Astronomy of the Mamluks".

[4] See Kennedy, "Exact Sciences in Iran".

[5] See İhsanoğlu *et al*., eds., *Ottoman Astronomical Literature* (in Turkish). Much of the basic bio-bibliographical data in that work is now available in English in Rosenfeld & İhsanoğlu, *MAIC*.

[6] As a carrot, I mention that Jamil Ragep has recently discovered discussions of the possibility of a heliocentric universe in the writings of ʿAlī Qūshjī (d. 1474), namely, his Persian *Risāla dar ʿilm-i hayʾa* and its Arabic translation *al-Risāla al-Fatḥiyya*, prepared for Sultan Fātiḥ Meḥmet (Rosenfeld & İhsanoğlu, *MAIC*, nos. 845-A1-2): see Ragep, "Ṭūsī and Copernicus".

[7] See Adıvar, *Science ottomane*, pp. 28, 35, 43-52; the numerous references in İhsanoğlu *et al*., eds., *Ottoman Astronomical Literature*, II, p. 992; as well as King, "Ottoman Timekeeping", pp. 247-248.

[8] On the latter see King, "Ottoman Timekeeping", and the more detailed investigation in **II-14**.

[9] Preliminary descriptions of these have been prepared in Frankfurt as part of a larger project to document all medieval Islamic and European instruments—see King, "Instrument Catalogue", announced over a decade ago with much enthusiasm and still in preparation. For a table of contents of the catalogue and a bibliography of recent publications on instruments see: www.uni-frankfurt.de/fb13/ign/instrument-catalogue.html, with most

indication of having been influenced specifically by either of these two pieces.

1 An astrolabe by Mukhliṣ Shirwānī made in 1504/05

This piece—see **Figs. 1.1-2**—is preserved in the Museum of Islamic Art, Cairo, with inventory number 15360. It was formerly in the Harari Collection (no. 235?—last digit uncertain), but its earlier provenance is unknown. It is made of brass, with some silver and gold inlay. Its diameter is 18.3 cm, and its thickness 0.6 cm. It has been illustrated several times[10] but never "published".[11] It has the number 12 in the International Instrument Checklist.[12] I inspected it in 1992, but was not allowed to catalogue it or any of the other Cairo instruments. The following description, taken from §1.4.17 of my unpublished (and still incomplete) catalogue of medieval Islamic and European instruments, was therefore prepared *without* the appropriate *idhn*. Also, the Museum could not provide decent photos.

Description

This is an elegant instrument with *kūfī* inscriptions and is clearly in the Iranian tradition. It was made for Bāyazīd II in the year 910 H by an individual from Shirwan in the Caucasus.

The throne is elegantly and ornately decorated with foliate patterns in inlaid silver and gold. It has six lobes on each side. The suspensory apparatus is standard and appears to be original. The scale on the rim is divided 5°/1° and labelled for each 5° without hundreds or tens. There is a prominent peg at 315° on the mater to hold the plates (unusual). The mater itself is roughly engraved with the two base-diameters.

The rete is highly ornate; in fact, it is over-decorated and the actual positions of some of the star pointers are not completely clear. The equinoctial bar is rectangular and prominent. Both the rectilinear bar to the lower left of the left hand side of the equinoctial bar and the long pointer for *qalb al-asad* that is symmetrical to it with respect to the vertical diameter pass between a pair of substantial curved pointers in the form of a crab's claws. The basic design of the pairs of claws on either side has been embellished with a series of leaf-motifs. The lower equatorial bar has arcs of circles at each end, attached to the pointer for *qalb al-asad* on the right and

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Ottoman pieces listed in §2.3 (see now **XVIII**). Several Ottoman astrolabes are featured in *Kandilli Instrument Handbook* and *Paris IMA Catalogue*. A handlist of astrolabes is in Price *et al*., *Astrolabe Checklist*.

[10] On this instrument see already Gunther, *Astrolabes*, I, p. 126 (no. 12); Pope, ed., *Survey of Persian Art*, III, p. 2518, and VI, pl. 1399, illustrations also in Hartner, "Astrolabe", A, pls. [3]A-B (front and back); Mayer, *Islamic Astrolabists*, p. 83 (under "Shukr Allāh Mukhliṣ", with additional bibliography); and Muṣaylaḥī, *al-Asṭurlāb*, p. 61, and pls. 20-22 (front, back and inscriptions). The piece has been misdated to [8]91 Hijra [= 1486], but the date is clearly 910 Hijra [= 1504/05].

In the Institut für Geschichte der Arabisch-Islamischen Wissenschaften in Frankfurt am Main there is a rather inelegant modern copy of this astrolabe. In the description of it in Sezgin & Neubauer, *Wissenschaft und Technik im Islam*, II, p. 109, the date is interpreted as 1091 H [= 1680], and the dedicatee as (a mythical) Sulṭān ibn Aʿẓam ibn Bāyazīd, "wohl ein Nachkommen des osmanischen Sultans Bāyazīd II". Fortunately the authors refrained from trying to identify the name of the maker of this, the earliest and most spectacular Ottoman astrolabe.

[11] This means providing a technical description, and, where appropriate, comparing with other instruments. See further **XIIIa-3**.

[12] Price *et al*., *Astrolabe Checklist*, p. 11, *etc*.

Figs. 1.1-2: The front and back of the astrolabe of Mukhliṣ Shirwānī (#12). [From the L. A. Mayer Memorial Collection in Jerusalem *ca*. 1950, kindly provided by Dominique Brieux from the collection of the late Alain Brieux of Paris.]
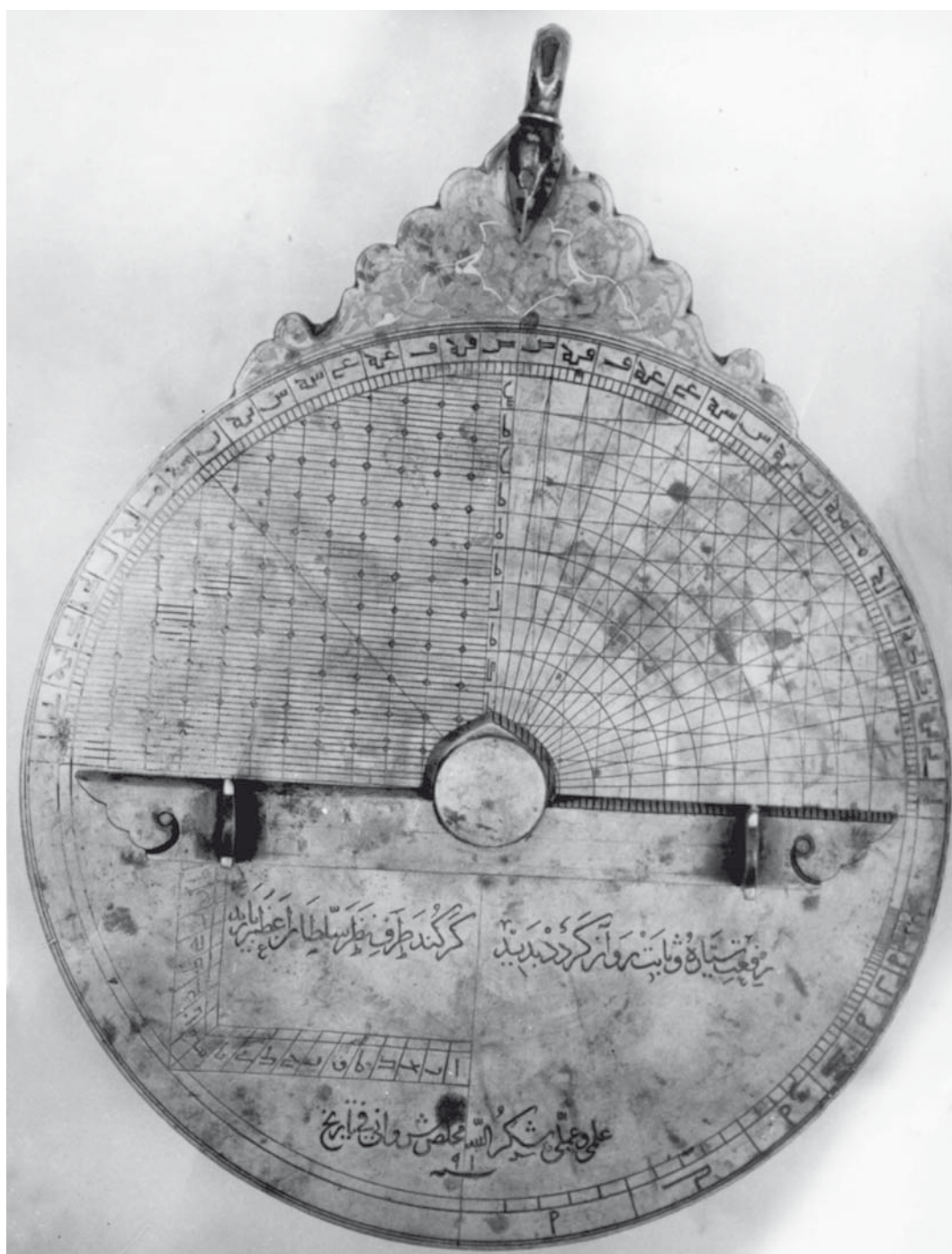
Fig. 1.2

to a dummy pointer on the left that extends as far as the ecliptic and bears a handle; it also yields to decorative frames at the middle—see below. Distinctive are the arched trefoil around the pointer for *al-wāqiʿ*, shaped like a bird with outstretched wings, and the similar bird-figures facing it inside and outside the ecliptic on the solstitial axis, as well as the heart-shaped configuration supporting one of these birds at the middle of the equatorial bar. The pointers for *fū qayṭus* and *fard al-shujāʿ* pass under the two circular arcs at the end of the equatorial bar, so devised as not to obscure the pointers. There is also a simple knotted design above the lower middle of the circumferential frame. There are no markings of consequence on the back of the rete.

The scale of the ecliptic is divided into 6°-intervals for each sign, subdivided into 3° and then 1°. The names of the first, third, ... , eleventh signs are inlaid in gold. There are pointers for 26 named stars, here listed in order of increasing right ascension (counter-clockwise from the vernal equinox) and to some extent identified using Paul Kunitzsch's lists of astrolabe stars (problem stars are boxed):[13]

Star		Kunitzsch nos.	Designation
1	*dhanab al-ḥūt*	Ø	identification uncertain
2	*ghūl*	9/14	β Persei
3	*fū qayṭus*	Ø	γ Ceti
4	*ʿayn al-thawr*	24/18	α Tauri
5	*ʿayyūq* (no sharp pointer)	10/20	α Aurigae
6	*rijl*	37/19	β Orionis
7	*yad*	36/22	α Orionis
8	*al-shiʿrā al-yamānī* (no obvious pointer)	39/23	α Canis Maioris
9	*al-shaʾāmiya* (pointer at right side of leaf; see also no. 10!)	40/25	α Canis Maioris
10	*al-safīna* (for *taraf al-safīna*)	Ø/27	ρ Puppis
11	*al-shaʾāmiya* (star repeated (see no. 9), and incorrectly situated on the ecliptic!)	40/25	α Canis Minoris
12	*fard al-shujāʿ*	42/29	α Hydrae
13	*al-qafza*	Ø/K56	ν ξ (or only ν) Ursae Maioris
14	*qalb al-asad*	26/30	α Leonis

[13] The numbers are those in Kunitzsch, "al-Ṣūfī and the Astrolabe Stars", pp. 158-161, and *idem*, *Arabische Sternnamen*, pp. 59-96. It is a pleasure to thank Professor Paul Kunitzsch (Munich) for his assistance with some of the non-standard stars featured on this astrolabe.

15	*al-bāṭiya*	Ø/32	α Crateris
16	*al-simāk al-aʿzal*	29/39	α Virginis
17	*al-rāmiḥ*	1/41	α Bootis
18	*al-fakka*	2/45	α Coronae Borealis
19	*qalb al-ʿaqrab*	30/48	α Scorpii
20	*al-ḥawwāʾ*	11/51	α Ophiuchi
21	*al-wāqiʿ*	4/53	α Lyrae
22	*al-ṭāʾir*	13/54	α Aquilae
23	*janāḥ al-dajāja*	Ø	ε Cygni (?)
24	*dhanab al-jad[y]*	32/59	δ Capricorni
25	*al-mankib*	17/62	β Pegasi
26	*dhanab qayṭus*	35/4	ι Ceti

The selection of stars is reminiscent of that on the Oxford rete of Jalāl al-Kirmānī (see **XIVd-2**).

The plates bear altitude circles for each 3° and no azimuth circles, except for the plate for latitude 41°, which has azimuths for each 10° below the horizon (marked A- below). The altitude arguments appear twice, inside each of the two outer base circles and along the meridian up to the zenith, and the seasonal hours are also numbered twice in *abjad* notation. On the one plate the azimuth arguments are labelled beneath the horizon and "crescent". The words *al-maghrib* and *al-mashriq* are engraved below the horizon. The latitudes served are the following:

1a	21		-	
2a	30		-	
2b	33		-	
3a	36		14;30^h	[0]
3b	38		14;42	[0]
4a	40		14;50	[-4]
4b	41	A-	15	[-1]

The lengths of daylight are promised on all plates. Those that are given, or at least the first two, are based on the Ptolemaic obliquity 23;51° (!). The value 14;50^h for latitude 40° may have been computed with the preferred Ottoman obliquity value 23;29° (accurately 14;51^h), and the value 15^h for 41° is simply a (reasonable) approximation (as well as a gentle reminder that Istanbul was thought to be at the middle of the 5th climate). The altitude circles are rather crudely engraved given the overall elegance of the instrument—in particular the fact that the *ṣād* for 90 has been written cosily inside the circle for 87° is proof that the upper circles are somewhat distorted. The shapes of some of the *abjad* numerals are unusual, especially those for 3, 8 and 9. Each of the plates has a cut-out in a position so that it fits the unusually-situated peg on the mater, and so the astrolabic markings are engraved on both sides of each plate so that the

meridians line up perfectly with the scale on the rim. Two of the latitudes have been repeated in *modern* Arabic numerals—see below.

Plate 1b bears four sets of half-horizons, rather roughly engraved. The declination scales are divided for each degree on either side of the equatorial circle but the divisions are not labelled. The latitudes served are:

20	25	32	38	43	46	
24	30	36	44	48	54	60
28	36	39	45	54	58	
66	70	75	80	85	90	

Note that there is some repetition and several awkward gaps in the latitudes.

The back has two altitude scales, with two sexagesimal (base 60) sine quadrants on the upper half. The one on the left has equi-spaced lines horizontal lines for each unit and equi-spaced verticals for each five units, with bold dots at the intersections for each 5 units. The one on the right has quarter-circles, horizontals and verticals for each 5 units on the right. The arguments 5—10—15 are written below the right-hand side of the vertical diameter. On the first quadrant, the radius is drawn for argument 45°: it is not clear why. In the lower left quadrant there is a shadow square (base 12) with a scale divided and labelled for each digit, and the remaining quadrant is empty of astronomical markings but for a shadow-scale (again to base 12) on the rim, which is divided for each 5 units, labelled and subdivided into single units, up to 50.

There are two inscriptions across the lower half of the back.[14] The upper one consists of two rhymed strophes in Persian, and it reads:

رفعت سيارة و ثابت روان كرداد بديد | كر كند طرف نظر سلطان اعظم بايزيد

*Rifʿat-i sayyāra vu thābit ravān gardad padīd**
gar kunad ṭarf-i naẓar sulṭān-i aʿẓam Bāyazīd
(metre: --∪----|--∪----|--∪----|--∪----)
* written *badīd*

which translates roughly:

> "If the greatest (of all) sultan(s), Sultan Bāyazīd, casts a glance (at the sky with this astrolabe), the elevation of the planet(s) and the motion of the fixed star(s) will become manifest."

This inscription displays some poetic licence and reflects a rather naïve understanding of what one can do with an astrolabe. Below this is an inscription in rather curious, even awkward, Arabic:

علمي وعملي شكر الله مخلص شرواني في تأريخ ٩١

ʿilmī wa-ʿamalī shukr Allāh mukhliṣ shirwānī fī taʾrīkh sanat 910

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[14] It is a pleasure to acknowledge the help of my friend Sergei Tourkin of The Oriental Institute, St. Petersburg, in reading and interpreting the Persian inscription as well as in pointing to the fact that the expression *shukr Allāh* in the Arabic inscription is not necessarily a personal name.

Taking the first two words as adjectives used adverbially, certainly an unhappy usage, and rendering them as verbs, this could be translated:

"Devised and constructed by Shukrallāh Mukhliṣ Shirwānī
in the year dated 910 (Hijra) [= 1504/05]."

As such, the maker of this astrolabe has been recorded in L. A. Mayer's *Islamic Astrolabists*, and I confess that this was my first reading of the inscription. But there is more to this inscription: see the commentary below.

The date is written in Hindu-Arabic numerals, which is unusual: alphanumerical (*abjad*) notation would be more in the medieval tradition. Also, the dot for zero—which could also be taken as the dot on the *nūn* (= *n*) in the word *sana(t)*—is written lower than normal, that is, "on the line", which caused previous researchers to interpret the date as 91, that is, [8]91, corresponding to 1486. This error has percolated through the literature.[15]

The alidade is straight with clef-shaped ends and one half-axis has a scale divided into about 60 units, even around part of the central semi-circular protrusion. It is unduly thick and barely reaches the degree scale but it does not seem to be a replacement. The sights have a flattish circular cutout on the top and one hole at the middle. The pin has a flat cylindrical head and a spherical knob at the bottom, and the wedge is a fine horse's head (without ears) attached to a collar at the end of a roughly rectangular piece.

It is always advisable to treat later additions separately. In this case, the plates for 21° and 38° have the latitudes repeated by an incompetent in *modern* Arabic numerals: 21 and 18 (*sic*).

Commentary

The use of Persian in the inscriptions reflects not only the background of the maker but also the cultural interests of the Ottoman court, and perhaps, no less, the influence of the Samarqand school on astronomy in Istanbul.

It is beyond the scope of this study to discuss the design of the rete in any more detail. There are many influences, mainly Iranian, visible here, but these are not properly documented yet, and I shall avoid comparisons with other surviving instruments. Suffice it to say that the elegant design is unusual and original, indeed it is unique amongst known Ottoman astrolabes.

The choice of stars is curious, some of them not being attested on other known astrolabes and/or not featured in the standard medieval or modern astrolabe stars. (Compare **XIVd-2**.) In particular, there are problems with the identification of *dhanab al-ḥūt* (no. 1); the pedantic orthography of *fū qayṭus* (no. 3), for which most astrolabists would have written *fam qayṭus*; the confusion between two stars labelled *al-shaʾāmiya* (nos. 9 and 11). The stars *dhanab al-ḥūt* (no. 1), *fū qayṭus* (no. 3), *al-qafza* (no. 13) and *janāḥ al-dajāja* (no. 23) are not listed in Kunitzsch's studies of astrolabe stars. It would be interesting to know which medieval star-list the maker used, presumably one in a text on astrolabe construction. None that is relevant comes to mind.

No localities are associated with the plates for specific latitudes. However, the plate for latitude

[15] See also n. 10 above on a very recent (2003!) misdating of this piece to 1081 H!

21° would serve Mecca; 30°, Cairo; 33°, Damascus and Baghdad; 36°, Aleppo and Mosul; 38°, Konya and Malatya; 40°, Bursa and Sivas; and 41°, Istanbul. The last is a good value for Istanbul: see **II-14.4**.

The two sine quadrants and shadow-square and circumferential shadow scale on the back are standard. The radius at argument 45° on the left quadrant does not seem to be related to the determination of the *ʿaṣr* prayer.[16]

We now return to the inscription mentioning the maker:

علمي وعملي شكر الله مخلص شرواني في تأريخ ٩١

ʿilmī wa-ʿamalī shukr Allāh mukhliṣ shirwānī fī taʾrīkh sanat 910 ,

which one could render:

"Devised and constructed by Shukrallāh Mukhliṣ Shirwānī"
in the year dated 910 (Hijra) [= 1504/05]."

The name Shukrallāh is indeed attested in both Safavid Iran and Ottoman Turkey.[17] However, I do not think that the combination and juxtaposition of two names of this kind, Shukrallāh and Mukhliṣ, is appropriate.[18] Furthermore, there is another possible reading of the same consonantal clusters, admittedly as problematic from a grammatical point of view as the first:

ʿilmī wa-ʿamalī shukran li-'llāh ... ...

so that the meaning would be something like:

"For my knowledge and my handiwork thanks be to God.
(Signed by) Mukhliṣ Shirwānī in the year dated 910 (Hijra)."

These considerations and renditions do not take into consideration the large *ḍamma* (*u* vowel) over the junction of the words *shukr* and *Allāh* or *shukran* and *li-'llāh*. This would imply a reading *shukr*^{un} *li-'llāh*, "thanks (be) to God", or the name *Shukrallāh*, both in the nominative. But somehow a meaning like:

"My knowledge and my handiwork are (my way of) thank(ing) God ..."

seems inappropriate. We should also note that the consonantal ligature *sīn-rāʾ* (*s-r*) is engraved below the word *shukr*, and, also, apparently, across the final *yāʾ* (*y*) of *ʿamalī*.

I suspect that there is more to this inscription than first meets the eye. We find the combination of the concepts *shukr*, *ʿilm* and *ʿamal* in the *Iḥyāʾ ʿulūm al-dīn*, "The Revival of the Religious Sciences", of the theologian al-Ghazālī (1058-1111).[19] *Shukr*, "gratitude", and its pre-requisite *ṣabr*, "patience or endurance", are here characterized as two halves of *īmān*, "faith". There are

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[16] Other such markings for this purpose are now studied in Charette, *Mamluk Instrumentation*, pp. 176-179.

[17] See the index of names in EI_2. Note also the names *Shukrī* and *Ṣabrī*, attested in Turkey and Egypt in more recent times.

[18] See King, *Mecca-Centred World-Maps*, pp. xxv-xxvi, and 255-262, for some reflections on the use of double names in Persian. One of the two maps in that book was signed by a certain Muḥammad Ḥusayn, and I hypothesized that another set of unsigned Safavid instruments might have been made by a Ḥasan Ḥusayn. Since that book appeared another Safavid world-map has come to light: it is signed by Ḥasan Ḥusayn. See further **VIIc**.

[19] I have relied on the article "Shukr" by Alma Giese in EI_2.

three parts to *shukr*. The first is *ʿilm*, "knowledge", characterized as "the real understanding that nothing except God has existence in itself, that the whole universe exists through Him and that everything that happens to a person (including afflictions) is a benefaction from Him". The second is *ḥāl*, "(the right) state", a state of joy in this benefaction with the associated conditions of humility and modesty (and sincerity—see below). The third is *ʿamal*, "action", in sense of "action in accordance with the state of joy deriving from complete knowledge of the benefactor", which has three aspects: the (hidden) action of the heart which is intending the good; the (manifest) action of the tongue which is praise of God; and the action of the members of the body, which is using them in obedience for Him ...". The opposite of *shukr* is *kufr*, "ingratitude for God's mercy", which is disbelief. If these notions are behind the inscription, then perhaps it means something like:

"My knowledge (of God's benefaction) and my actions (in obedience to Him) are (aspects of my) gratitude for (the unlimited mercy of) God."

If this is the case, then the rest of the inscription, which lacks a verb, is just a sort of dated signature. And even though the name Mukhliṣ, "sincere", relates to an appropriate "state", I would not be inclined to deny that this is the name of the astrolabist whose family origins were in Shirwān.

The maker is unknown to all of the modern bio-bibliographical sources except L. A. Mayer's *Islamic Astrolabists* (1956).[20] But both his name and the year when he completed this astrolabe are apparently incorrectly given.

2 An astrolabe made by al-Aḥmar al-Nujūmī al-Rūmī in 1505/06

This instrument, previously unrecorded, became available for study in 1998, when it was auctioned at Sotheby's in London: see **Figs. 2.1-4**.[21] It aroused no interest and was not sold, a poor reflection on the seriousness of the interests of those museums and private persons currently collecting Islamic artefacts. It has been assigned no. 4218 in the International Instrument Checklist.

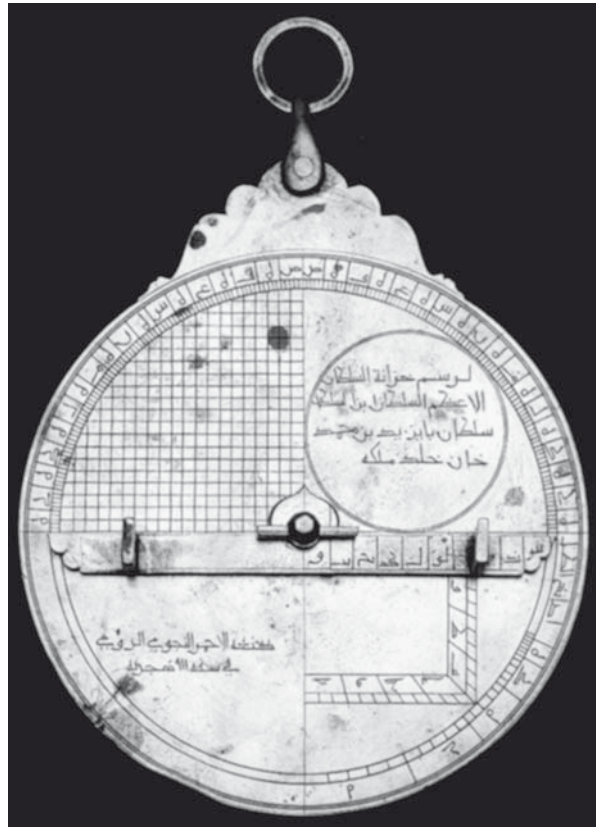
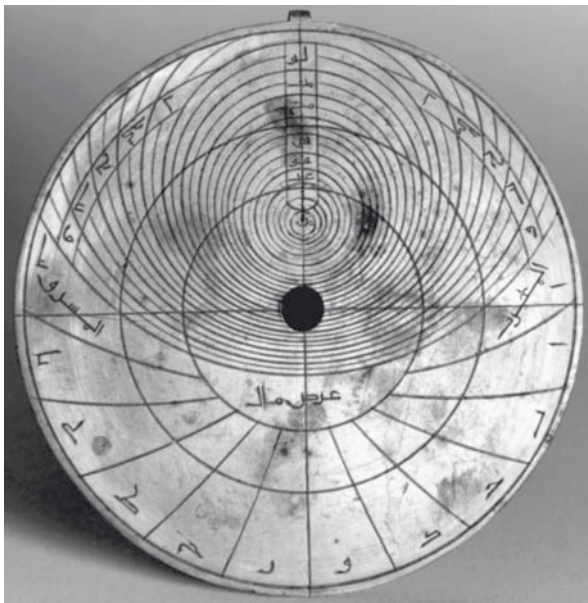
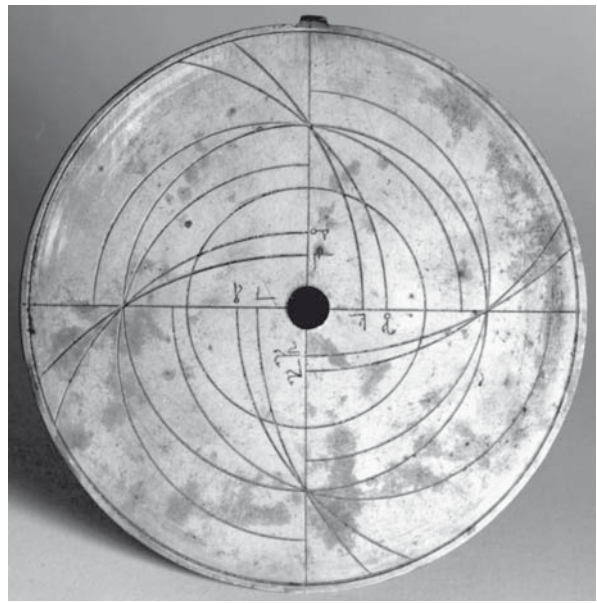
Description

The diameter is 9.5 cm and the thickness 0.6 cm. The workmanship is competent but not first-rate. This is an astrolabe to be used, not looked at. The engraving, in *kūfī*, is elegant and distinctive. The Arabic alphanumerical (*abjad*) notation is used throughout, except for the date, which is written in Hindu-Arabic numerals.

The throne is undecorated, with two lobes on either side of the upper lobe and smaller protrusions (in the form of a horse's head?) at the far left and right. The suspension apparatus, a shackle and ring, is attached at the top of the throne.

The mater bears a circumferential scale divided for each 5° and subdivided for each 1°, labelled

[20] See n. 10 above.

[21] This description is taken from *Sotheby's London 15.10.1998 Catalogue*, pp. 68-71 (lot 94), written by this author.

2.1 2.2 2.3 2.4

Figs. 2.1-4: The front and back of the astrolabe of al-Aḥmar al-Nujūmī al-Rūmī (#4218), as well as the plates for latitude 41;30° and a set of horizons. [Photos courtesy of Sotheby's of London.]

5°—10°—5°—20°—...—5—[3]60°. The base circles for the equinoxes and two solstices are engraved in the inside of the mater. (This was a common practice, which enabled additional markings to be added at will.)

The rete is of unusual design. It is simple and barely decorated. The horizontal diameter is rectilinear (not counter-changed), as was standard on early Eastern Islamic astrolabes. The vertical axis is complete, but incorporates some decorative features. Above the centre, there is a heart-shaped, or perhaps rather hoe-shaped, frame in the upper half of the ecliptic (not known on any other astrolabe). Above this is a flower-shaped design with six petals, at the centre of which is a silver knob, which serves, along with three others, two at either end of the horizontal diameter and another below the centre, to turn the rete over the appropriate plate. The earlier development of these designs can be traced (see the commentary below).

The scale of the ecliptic is divided for the zodiacal signs, whose names are the standard forms:

al-ḥamal—al-thawr—al-jawzāʾ—al-saraṭān—al-asad—al-sunbula
al-mīzān—al-ʿaqrab—al-qaws—al-jady—al-dalw—al-ḥūt ,

and each sign is divided into five unlabelled 6°-intervals. The star-pointers are shaped like jester's hats, developed—as if by lack of starching—from the dagger-shaped pointers on early Eastern Islamic astrolabes. They serve 15 named stars, all standard astrolabe stars, listed here as on the first astrolabe discussed above:[22]

Star		Kunitzsch nos.	Designation
1	*al-dabarān*	24/18	α Tauri
2	*rijl al-jawzāʾ*	37/19	β Orionis
3	*(al-shiʿrā) al-yamāniya*	39/23	α Canis Maioris
4	*(al-shiʿrā) al-shaʾāmiya*	40/25	α Canis Minoris
5	*qalb al-asad*	26/30	α Leonis
6	*(al-simāk) al-aʿzal*	29/39	α Virginis
7	*(al-simāk) al-rāmiḥ*	1/41	α Bootis
8	*ʿunuq (al-ḥayya)*	12/196	α Serpentis
9	*?? fakka*	2/45	α Coronae Borealis
	(first word illegible: one would expect *al-munīr min al-fakka* or *nayyir al-fakka*)		
10	*qalb al-ʿaqrab*	30/48	α Scorpii
11	*(raʾs) al-ḥawwāʾ*	11/51	α Ophiuchi
12	*(al-nasr) al-ṭāʾir*	13/54	α Aquilae
13	*dhanab al-dajāja*	6/56	α Cygni
14	*dhanab al-jady*	32/59	δ Capricorni
15	*mankib (al-faras)*	17/62	β Pegasi

There are three plates with five sides engraved with altitude-circles for each 3°, labelled for each 6°. The altitude arguments are engraved in lined "cartouches" on the left and right,

[22] The numbers are those in Kunitzsch, "al-Ṣūfī and the Astrolabe Stars", pp. 158-161, and *idem*, *Arabische Sternnamen*, pp. 59-96, also p. 217 (for no. 8).

continuing down the centre (*i.e.*, up the meridian) to the zenith, which is labelled 90° within the altitude circle for 84°. Such cartouches are found already on some of the plates of 10th-century astrolabes. The east- and west-points are labelled *al-mashriq* and *al-maghrib* below the horizon. The curves for the seasonal hours below the horizon are labelled 1, 2, ... , 12. (On the plate for 41;30° the "1" has been repeated but the mistake realised: the numbers run 1-1-2-3-4-6- ... .) The astrolabic markings serve latitudes:

1a	33°
2a	36°
2b	39°
3a	40°
3b	41;30°

The latitudes are indicated by the expression *ʿarḍ* —, "latitude —". No localities are associated with these, but see the commentary. On side 1b is a set of half-horizons arranged in four quadrants and marked for latitudes:

28° / 38° 33° / 48° 32° / 45° 30° / 43°.

The back is simply executed. Above the horizontal diameter there are two altitude scales with divisions labelled for each 5°, subdivided for each 1°. In the upper left quadrant is a sexagesimal trigonometric grid with equi-spaced horizontal and vertical lines drawn for each 3 units. In the upper right quadrant, the dedication is engraved within a double circle. The rim of the lower left quadrant is devoid of markings and in this quadrant the name of the maker is engraved on a single line. The rim of the lower right quadrant is marked with a scale for shadows to base 12 and is labelled *ẓill-i aṣābīʿ*, "shadow in digits". The scale begins at the bottom and is marked up to 25 digits, each 5 being labelled, with subdivisions for each 1 unit. Inside this quadrant. there is a shadow square to base 12 with horizontal and vertical scales divided and labelled for each 3 units (digits), subdivided for each single unit.

The dedication reads:

لرسم خزانة السلطان الأعظم السلطان بن السلطان سلطان بايزيد بن محمد خان خلد (الله) ملكه

li-rasm khizānati 'l-sultāni 'l-aʿẓam al-sulṭān ibn al-sulṭān
sulṭān Bāyazīd ibn Muḥammad Khān khallada [*'llāh*] *mulkahu*
"By order of the Treasury of the Greatest Sultan, sultan son of sultan,"
Sultan Bayezit son of Mehmet Khan—may [God] make his dominion last for ever."

The inscription naming the maker reads:

صنعه الأحمر النجومي الرومي في سنة ٩١١ هجرية

ṣana'ahu 'l-Aḥmar al-Nujūmī al-Rūmī fī sanati 911 Hijriyya,
"Constructed by al-Aḥmar al-Nujūmī al-Rūmī in the year 911 Hijra [1505/06]."

The date is written in Hindu-Arabic numerals.

The alidade is not counter-changed and is decorated with clef-shaped ends. There is a sexagesimal scale on one half of the alidade, labelled 6-12-...-54-60, for use in conjunction with the trigonometric quadrant on the back.

Commentary

The basic simplicity of the rete is in the tradition of some of the non-presentational pieces from Mamluk Syria, such as the one (#6) made by the Damascus astronomer Ibn al-Shāṭir in 726 H [= 1325/26] (**XIVb-4**). The flower on the rete can be traced back to the decorative quatrefoil on the spectacular astrolabe (#111) of the astronomer al-Khujandī, made in Baghdad in 374 H [= 984/85] (**XIIIa-9** and also **XVII-1**). This quatrefoil, probably Byzantine in inspiration, is found on several astrolabes from the Islamic East over the centuries. On this piece, the substitute for the quatrefoil occurs above a cardioid frame enclosing the star-pointer for Vega, graphically represented as an eagle. Various later Eastern Islamic astrolabes show this combination of motifs, which on this astrolabe for Bayezit II appear in a more simplified form.

The 15 stars selected are standard astrolabe ones, in fact, they constitute a subgroup of the 17 stars used on Greek and the earliest Islamic astrolabes from the 8^{th}-10^{th} centuries (**XIIIb-2.5**, and **XIIIc-1.1-2**).

The plate for 33° could serve Damascus and Baghdad; 36°, Aleppo and Mosul; 39°, Kayseri, Konya (?) and Ankara; 40°, Bursa and Sivas. The plate for 41;30° was clearly intended for Istanbul, although the latitude of that city is correctly 41°2′. There were severe problems with medieval values for the latitude of Constantinople, which was often taken as 45°,[23] and Ottoman astronomers were the first to measure it properly. This seems to have escaped our al-Aḥmar.

The maker, al-Aḥmar al-Nujūmī al-Rūmī is unknown to the modern literature on Islamic instrumentation. His personal name is unusual and means "the red one"; nevertheless, the name Aḥmar is an attested Muslim name.[24] The epithet al-Rūmī indicates that he was a Turk from the Central Anatolia.[25] The epithet al-*nujūmī* indicates that he was an astronomer and/or astrologer, yet he is not mentioned in the new bio-bibliographical survey of Ottoman astronomers and their works.[26] This means only that he did not author any treatises.

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[23] Sere further Kennedy & Kennedy, *Islamic Geographical Coordinates*, pp. 93-94; and King, "Byzantine Astronomy".

[24] See the index of names to EI_2; also Brockelmann, *GAL*, III, p. 555.

[25] Article "Rūmī" by Halil Inalcik in EI_2.

[26] See n. 5 above.

Part XIVf

Brief remarks on astronomical instruments from Muslim India

To Professor Sreeramula Rajeswara Sarma

DEDICATION,
ACKNOWLEDGEMENTS AND NOTES TO THIS VERSION

This study results from a lecture given at a conference held in both Hyderabad, Deccan, and Jaipur in 1991. The written version "Indian Astrolabes, Quadrants and Sundials in the Context of the History of Astronomical Instrumentation" was submitted to the *Proceedings*, which were, however, never published.

Much of what I have to say on Indian instruments is rendered redundant by the more recent, and more profound research of my esteemed colleague Professor Sreeramula R. Sarma of Aligarh Muslim University. Professor Sarma is well on the way to producing a *Gesamtkatalog* of all instruments produced in India, with inscriptions in Arabic, Persian and Sanskrit. I am therefore slightly embarrassed to dedicate this paper, which was worth more in 1991, before he started his project, than it is now, to Professor Sarma. However, in so doing, I take the opportunity to list his publications that are relevant to this subject, some of which might not otherwise reach the attention of Western scholars. His publications and his present research have already laid a firm foundation for the future study of Indian instruments. We note:

- Yantraprakāra *of Sawai Jai Singh,* ed. and transl., suppl. to *Studies in History of Medicine and Science* (Jamia Hamdard, New Delhi) 10-11 (1986-87).
- "Astronomical Instruments in Brahmagupta's *Brāhmasphuṭasiddhānta*", *Indian Historical Review* 13 (1986-87), pp. 63-74.
- "Astronomical Instruments in Mughal Miniatures", *Studien zur Indologie und Iranistik* 16-17 (1992), pp. 235-276.
- "Two Mughal Celestial Globes" (with S. M. R. Ansari and A. G. Kulkarni), *Indian Journal of History of Science* 28:1 (1993), pp. 80-89.
- "Indian Astronomical and Time-Measuring Instruments: A Catalogue in Preparation", *Indian Journal of History of Science* 29:4 (1994), pp. 507-528.
- "From al-Kura to Bhagola: On the Dissemination of the Celestial Globe in India", *Studies in History of Medicine and Science* (Jamia Hamdard, New Delhi) 13:1 (1994), pp. 69-85.
- "The Lahore Family of Astrolabists and Their Ouvrage", *Studies in History of Medicine and Science* (Jamia Hamdard, New Delhi) 13:2 (1994), pp. 205-224.
- *Astronomical Instruments in the Salar Jung Museum,* Hyderabad: Salar Jung Museum, 1996.
- "The *Ṣafīḥa Zarqāliyya* in India", in *From Baghdad to Barcelona. Studies in the Islamic Exact Sciences in Honour of Prof. Juan Vernet*, Josep Casulleras and Julio Samsó, eds., 2 vols., Barcelona: Instituto "Millás Vallicrosa" de Historia de la Ciencia Árabe, 1996, pp. 718-735.
- "Yantrarāja: the Astrolabe in Sanskrit", *Indian Journal of History of Science* 34 (1999), pp. 145-158.
- "Kaṭapayādi Notation on a Sanskrit Astrolabe", *Indian Journal of History of Science* 34 (1999), pp. 273-287.
- "A Brief Introduction to the Astronomical Instruments in Khuda Bakhsh Library, Patna", *Khuda Bakhsh Library Journal* 118 (Dec., 1999), pp. 1-10.
- "Sulṭān, Sūri and the Astrolabe", *Indian Journal of History of Science* 35 (2000), pp. 129-147.

- “Some Indo-Persian Astronomical Instruments of the Early Nineteenth Century”, *Khuda Bakhsh Library Journal* 123 (April, 2001), pp. 1-16.
- *Astronomical Instruments in the Rampur Raza Library*, Rampur: Rampur Raza Library, 2003.
- “Instrumentation for Astronomy and Navigation in India at the Advent of the Portuguese”, to appear in the Proceedings of the 9th International Indo-Portuguese History Seminar on Discoveries, Technology & Culture, Indian National Science Academy, New Delhi.

I also thank my friend and colleague Professor S. A. Raza Ansari of Aligarh for keeping me informed of his research on the Islamic manuscript tradition relating to Indian astronomical instruments.

On the occasion of the 1991 Hyderabad and Jaipur symposium I was able to conduct research on astronomical instruments in the Red Fort Museum in New Delhi, the Salar Jung Museum in Hyderabad, and the Observatory Museum in Jaipur. It is a pleasure to thank Dr. C. Margabandhu, Director of the Archaeological Survey of India in New Delhi; the Deputy-Superintending Archaeologist of the Red Fort Museum; Dr. N. L. Nigam, Director, and Dr. Rehmet Ali Khan, Keeper of Manuscripts of the Salar Jung Museum in Hyderabad and Mr. Yaduendra Sahai, Director of the Sawai Mansingh II Museum in Jaipur, and their respective staffs, for their kindness and collaboration. My visit to India in December, 1991, was made possible by the Goethe Institute in Munich, and it is a pleasure to thank Dr. J. P. Bumke of the Max Mueller Bhavan in Hyderabad for arranging my visit. To Dr. B. G. Sidharth, Director of the B. M. Birla Planetariums and Science Museums in Hyderabad, my admiration for his splendid organization of the Symposium and my gratitude for his generous hospitality.

In addition to those authors cited in the notes below, credit should also be given to Nabia Abbott, George R. Kaye, Robert T. Gunther, V. Govind and K. Behari, and S. S. Nadvi, for their work on Indian instruments and their makers:

- Nabia Abbott, “Indian Astrolabe Makers”, *Islamic Culture* 11 (1937), pp. 144-146.
- K. Behari and V. Govind, “A Survey of Historical Astrolabes”, *Indian Journal of History of Science* 15:1 (1980), pp. 94-104.
- V. Govind, “A Survey of Medieval Indian Astrolabes”, *Bhāratīya Vidyā* (Bombay: Bharatiya Vidya Bhavan), 39:1 (1979), pp. 1-30.
- George R. Kaye, “Astronomical Instruments in the Delhi Museum”, *Memoirs of the Archaeological Survey of India*, no. 12, Calcutta: Superintendent Government Printing, India, 1921.
- *idem*, *The Astronomical Observatories of Jai Singh,* (*Archaeological Survey of India*, New Imperial Series, vol. XL), and *A Guide to the Observatories at Delhi, Jaipur*, *etc*., Calcutta, 1918 and 1920, both repr. in *IAM*, vol. 93.
- S. S. Nadvi, “Some Indian Astrolabe-Makers”, *Islamic Culture* 9 (1935), pp. 621-631, with additional notes *ibid*., 11 (1937), pp. 537-539.

In this version, I have added some materials from the recently-published catalogue of the Nasser D. Khalili collection in London (listed as *London Khalili Collection Catalogue*) and from my review thereof (in *Bibliotheca Orientalis* 57 (2000), cols. 247-258). The collection is particularly rich in Indo-Persian instruments.

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1 Introductory remarks

Astronomical instruments made in the Indian subcontinent form a small but significant part of a corpus of surviving medieval instruments; several dozen out of a total of well over one thousand medieval instruments are Indian in provenance. These instruments include the celestial globe, astrolabe and sundial, which are related in that they are all based on principles known already in Antiquity; the quadrant, on the other hand, was invented in the early days of Islamic astronomy in Baghdad. It is convenient to think of all of these instruments as belonging to a "medieval" tradition that continued in the East (the Islamic world and India) until about 1900 and in Europe until about 1550.

Instrumentation in Muslim India seems to have begun with the influx of scholars from Central Asia after the establishment of the Delhi Sultanate after 1211. In particular, the Sultan Fīrūz Shāh Tughluq (1351-1388) promoted science and technology. Professor Sarma's very important 2000 study entitled "Sulṭān, Sūrī and the Astrolabe" contains new information on five astrolabes that were made for the Sultan, including a silver astrolabe and a brass north-south astrolabe with plates for the climates, a silver north-south astrolabe and another large one in brass, and a standard astrolabe in gold and silver. Alas, all these are lost, but details are available, such as the latitudes used for the plates. The surviving instruments all post-date *ca*. 1550 but are of interest not only because some of them are visually spectacular and mathematically accurate, but also because they preserve earlier features not known from other surviving instruments. For example, some astrolabes of the Lahore school (17th century) show how the Lahore astrolabists revived complicated modifications to the standard astrolabe of Late Antiquity which had been devised in Baghdad in the 9th and 10th centuries but which, by the 17th century, were virtually forgotten by Muslim astrolabists everywhere except India. That these modifications were of considerable sophistication is shown by the fact that they were developed independently in Europe only in the 17th century.

2 A monumental astrolabe from 16th-century India

The oldest known astrolabe from Muslim India, alas neither signed nor dated, is a monumental 52.5 cm in diameter.[1] It is now in the Khalili Collection in London, and awaits detailed study. The inscriptions on this piece (#4301) are in both Arabic and Sanskrit, but the latter are not original and were squeezed in the limited space left by the elegant Arabic inscriptions. Thus, it was made by a Muslim, entirely in the Islamic tradition, albeit with considerable innovation, and later fell into the hands of a Hindu, who added some inelegant inscriptions in Sanskrit. The star-positions correspond to *ca*. 1550. Certainly, the piece is not obviously related to the *known* productions of the Lahore school. In fact, it represents a tradition about which we know virtually nothing. But it was made in either Delhi or Lahore, since the latitudes on the *zawraqī* horizons

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[1] *London Khalili Collection Catalogue*, I, pp. 230-233 (no. 133), and my notes in "Review", col. 254-255. No photos are available to me, and the catalogue has several excellent shots, but none of the full rete, the plates or the back.

on the rete are for latitudes 29° and 32°. The curves displaying solar meridian altitudes on the back serve latitudes 27°, 29° and 32°, the first serving perhaps Ajmer or Ahmadabad (the piece is too early to be associated with Jaipur). As yet we know of no astrolabes with Arabic inscriptions from Delhi. I strongly suspect that we have here the sole surviving work of Maqṣūd Hirawī in Lahore, *ca*. 1550, known to have been one of the instrument-makers to the Moghul Emperor Humāyūn, the son and successor of the Timurid conqueror of India, Bābur. According to a contemporaneous source, he "manufactured astrolabes and globes in such a manner that the observers of his works were wonderstruck".[2] Surely, this is one of them. I admit there is a problem with my logic, but this piece has to fit in somewhere. The mater is engraved with an extensive geographical table including qibla-values, which is the oldest Islamic Indian (non-Sanskrit) geographical table with qibla-values known to us.[3]

A description of this astrolabe alone would be worth a master's dissertation, but this could then lead to a book, for one could take Professor Sarma's 1994 paper on the Lahore astrolabists and their surviving productions as a guide and have a look of some of the unusual features of their astrolabes—such as *zawraqī* markings, which have still not been properly explained in the modern literature—in order to document their origins in earlier (that is, 9th- and 10th-century) textual sources

3 The first astrolabes of the Lahore school

Two astrolabes made by Allāh-Dād or Ilāh-Dād, perhaps the real founder of the Lahore school, and certainly the head of a large family of instrument-makers that extended over four generations, are preserved in Hyderabad[4] and Oxford.[5] See **Figs. 1a-b** and **2**. The former—studied for the first time during the Hyderabad symposium—attests to the fact that their maker was influenced by tradition of astrolabe-making in 15th-century Samarqand, of which we have but one surviving example.

It is surely relevant to the early development of the Lahore school under Maqṣūd Hirawī (whose family originally hailed from Herat) that:

(1) the astrolabe dedicated to Ulugh Beg by Jalāl al-Kirmānī (now in Copenhagen—see **XIVd-1**), the instrument-maker at his observatory in Samarqand, has special markings on the plates for the qibla at Samarqand and Herat, and that

(2) one of the two surviving astrolabes by Allāh-Dād (now in Hyderabad), the first member of the well-known Lahore family of astrolabists, bears a plate for Samarqand.

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[2] *London Khalili Collection Catalogue*, I, p. 219.

[3] See the remarks on Indian geographical tables in King, *Mecca-Centred World-Maps*, p. 154, also *idem*, "Review of *London Khalili Collection Catalogue*", cols. 254 and 255.

[4] See the description by Professor S. R. Sarma in *Hyderabad SJM Catalogue*, pp. 7-11 (no. 1) and pls. 1-3.

[5] *Oxford MHS Billmeir Catalogue Supplement*, pp. 20-21 (no. 159), and pl. XVIII.

Fig. 1a-b: The front and back of the Oxford astrolabe of Allāh-dād (#1089). The various frames on the rete are too wide to achieve any elegance. The two birds, for Vega and Altair, are cute but somewhat absurd. Note that there is an Ibn Bāṣo-type plate underneath the rete. On the back the solar scale has been left incomplete. [Courtesy of the Museum of the History of Science, Oxford.]
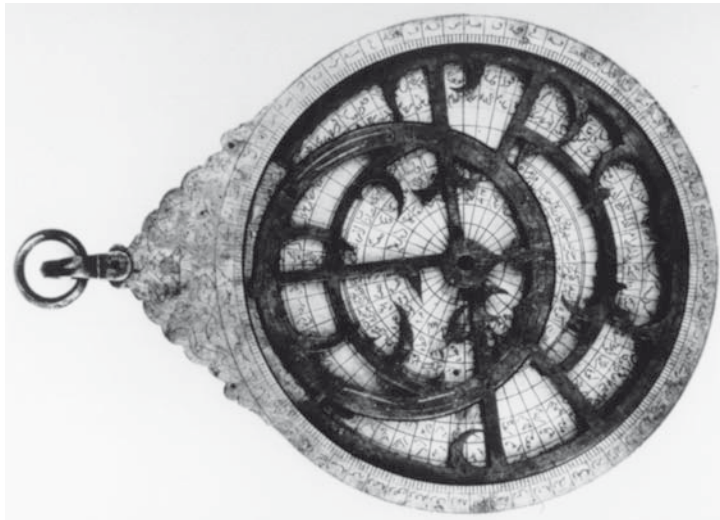
Fig. 2: The front of the Hyderabad astrolabe (#1120) of Allāh-dād. [Courtesy of the Salar Jung Museum, Hyderabad.]

4 The astrolabes of the Lahore school

The offspring of Allāh-Dād, whose activity seems to have stopped rather abruptly around 1690, produced mainly astrolabes and globes; dozens survive but few have ever been studied systematically.[6] **Figs. 3a-c** show the rete and back and some plates of an astrolabe by Jamāl al-Dīn, son of Muḥammad Muqīm, son of ʿĪsā, son of Allāh-Dād in 1077 Hijra [= 1666/67].[9] The zoomorphic features on the rete, the additional *zawraqī* horizon for a specific latitude on the rete, which could rotate over the ecliptic on the plate for latitude 66;30° if that ecliptic had been marked on the plate (but it was not!), the competently-executed complex markings on the various plates, and the various trigonometric, astronomical and astrological markings on the back are typical of the astrolabes of the Lahore school. On the back there are solar meridian altitude curves for four latitudes: 21° (for Mecca), 27° (for Jaipur?), 36° (for the fourth climate of antiquity, the middle of the inhabited world), and 40° (for Samarqand, a reminder of the maker's great-grandfather's ties to Samarqand. Why is there no curve for the latitude of Lahore? Does this mean that Jamāl al-Dīn was no longer working there? On the mater of this astrolabe there is a map of the known world arranged in such a way as to enable the user to find the qibla or direction of Mecca directly from the map.

Astrolabes were also made by Muslim craftsmen elsewhere in India, but we cannot expect to obtain an overview of this activity until at least the most important surviving pieces have been published by Professor Sarma. For example, one spectacular piece, 490 mm. in diameter and now in a private collection in London, appears to have been made in Delhi.[8] From the 18th century onwards, the main scene of activity was Jaipur. Some of the instruments with Arabic or Persian inscriptions now housed at the Observatory there were catalogued for the first time by the present writer and Professor Sarma after the Jaipur Symposium in December, 1991. There was, alas, no time for us to catalogue (or even see) the entire collection.

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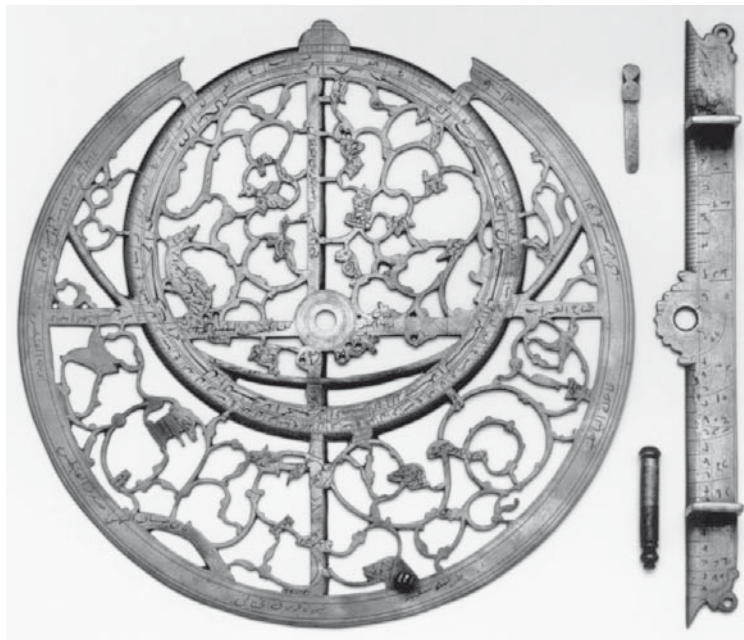
Figs. 3a-c: Parts of a remarkable astrolabe (#4143) by Jamāl al-Dīn ibn Muḥammad Muqīm ibn ʿĪsā ibn Allāh-dād dated in 1077 Hijra [= 1666/67]. [Courtesy of Sotheby's, New York.]

(a) The rete is remarkable for some zoomorphic features if not for its elegance.

(b) The mater is remarkable for a map of the world in the medieval tradition (but look at the coordinate grid!) intended for finding the direction of Mecca. See further King, *Mecca-Centred World-Maps*, pp. 95-96. The back is unremarkable. In the solar scale on the upper right, note the curve for latitude 27°, which serves Jaipur but not Lahore (or Delhi). The solar scale ends too close to the centre so that the curves sort of self-destruct.

[6] The best study of such an instrument remains Frank & Meyerhof, "Mogulisches Astrolab". See also Gunther, *Astrolabes of the World*, I, pp. 179-220. All of the Lahore instruments have been catalogued by Professor S. R. Sarma.

[7] The first description of an astrolabe that I prepared was for this piece (#4143): see *Christie's New York 31.10.1985 Catalogue*, pp. 94-95 (lot 331).

[8] See n. 1 above.

a

b

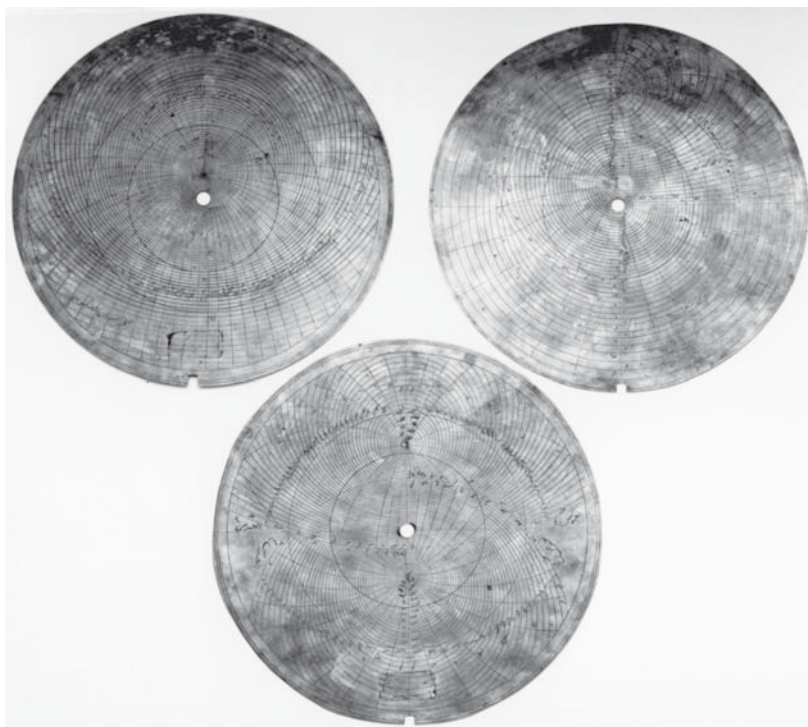



Fig. 3c: The main plates have altitude circles for each 2° or even 1°. Some of the plates are very remarkable. Shown here are one for converting celestial coordinates, and two as an exercise for the reader.

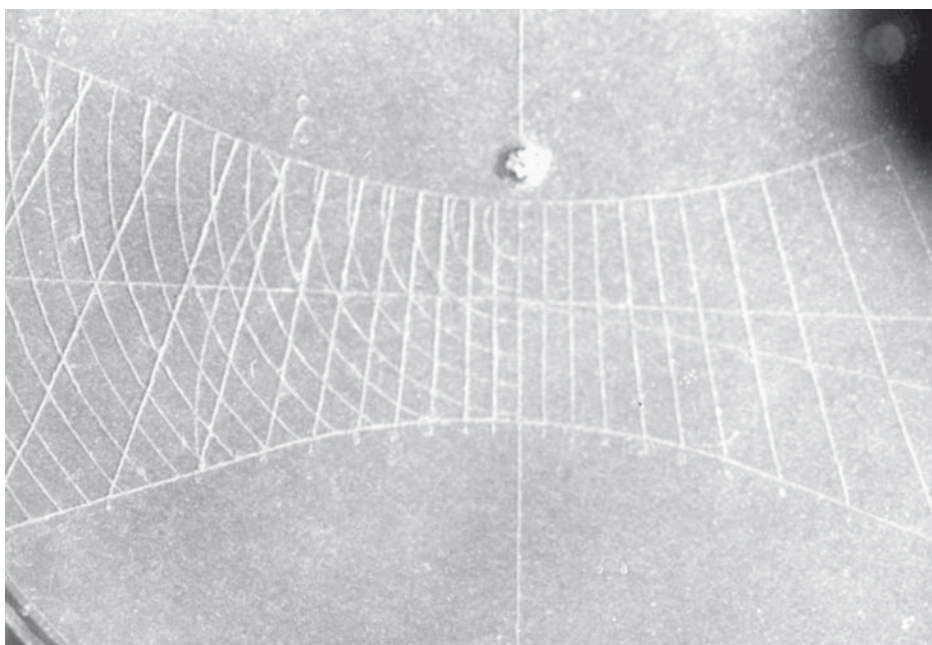



Fig. 4: The sundial in the Chahār Minār Mosque in Hyderabad (#7381). We see in addition to the hour-lines the markings for the daylight prayers and the qibla at Hyderabad (all Islamic) and a family of circular arcs around the gnomon to serve as a scale for measuring the length of the shadow (Indian). This sundial is in dire need of conservation. [Photo by the author, achieved by standing on top of the sundial.]

a

b

Fig. 5a-b: The front and back of a fake astrolabe by the "Bombay school". Note the double numerical notation on the outer rim of the mater (compare **Fig. XIVa-2.1**) and the very dubious markings on the mater beneath the rete. Two similar instruments from the same school are classified as "India, *circa* 1800" in *London Khalili Collection Catalogue*, I, pp. 237-238. At least they look more like real astrolabes than the piece of junk labelled "Isfahan 1706" that is illustrated in Sezgin & Neubauer, *Wissenschaft und Technik im Islam*, p. 110. [Photos courtesy of Christie's of London.]

Some Islamic astrolabes from Iraq and the Maghrib that ended up in India and were provided with additional Sanskrit inscriptions have been studied.[9] Minor details such as have never before attracted the attention or aroused the interest of previous investigators enable us to piece together the history of the individual instrument and relate it to the history of instrumentation in general.

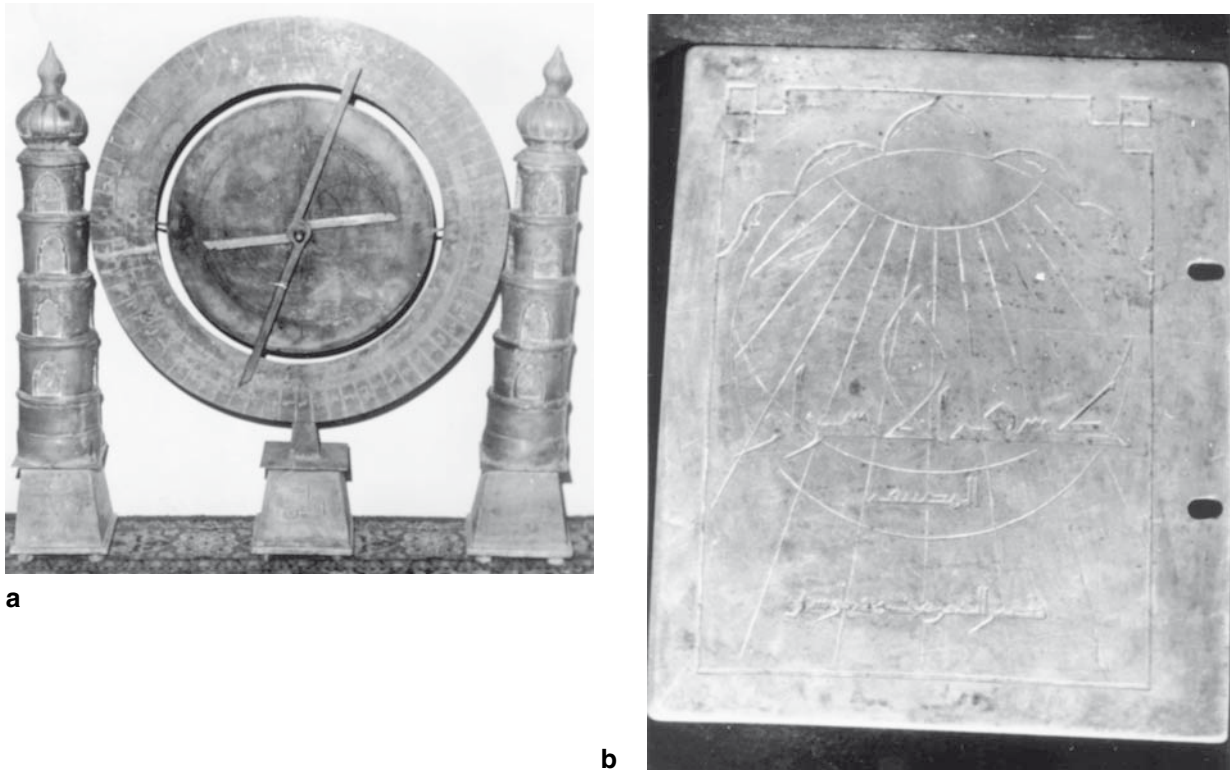
5 Astrolabes with inscriptions in Sanskrit

There are two main varieties of surviving astrolabes with Sanskrit inscriptions.[10] The larger group

[9] See, for two examples in addition to the most spectacular one cited in n. 3, *Linton Collection Catalogue*, pp. 121-123 (no. 179), on a curious astrolabe in the ʿIrāqī (especially al-Khujandī) tradition by Wafāʾī Munajjim (#2708), and Archinard, *Astrolabe*, pp. 20-36, on a 14th-century Maghribi astrolabe by ʿAlī ibn Ibrāhīm al-Jazzār (#4041).

[10] The best source for these is still Gunther, *Astrolabes of the World*, I, pp. 221-228, although a catalogue by Professor S. R. Sarma is forthcoming.

a

b

Figs. 6a-b: Samples of other products of the "Bombay school". The book purports to be the *Kashf al-asrār*, "The Reveleation of Secrets" by the 13th-century polymath Naṣīr al-Dīn al-Ṭūsī. [Photos courtesy of Christie's of London.]

bears astrolabic markings only for latitude 27°, serving Jaipur; the smaller one is characterized by a set of plates for different latitudes in the subcontinent. The star-positions on the distinctive retes of some of these instruments and the intricately-worked plates reveal that they were made with astounding accuracy. But there are also numerous examples made only for tourists. Several Indian astrolabes, mainly for the latitude of Jaipur, show up in European auction houses each year; one wonders how many of these were really made in Jaipur.

6 Other Indian instruments

Islamic globes, including several from Lahore and elsewhere in the subcontinent, have been surveyed by Emilie Savage-Smith.[11] No Indian quadrants with Arabic or Persian inscriptions are known; those with Sanskrit inscriptions are either for reckoning time in *ghaṭī*s, for trigonometric calculations or for astrological purposes. Various Indian sundials with Arabic or Persian inscriptions are known, mainly those in the Jāmiʿ Mosque in Delhi and the Chahār Minār

[11] Savage-Smith, *Islamicate Globes*, begins with a detailed description of one such Lahore globe.

Mosque in Hyderabad. The former displays European influence and the latter—see **Fig. 4**—is an interesting combination of Islamic and Indian traditions.

7 On modern fakes from India

In conclusion, a few remarks about fake instruments are in order. The faking of Islamic astrolabes has been going on for several decades. Some Persian fakes already feature in major Western museums, and most faking of Islamic astrolabes seems to have been conducted in Iran. The word "fake" can be applied to any instrument bearing a false inscription or made for the express purpose of deception; the word can also be used for any unsigned decorative astrolabe in an older style. (Modern replicas should be signed by their makers in order to distinguish them from deliberate fakes.) A new school of astrolabe fakers has recently appeared in India; I label it the "Bombay school" since most of the pieces I have seen were purchased in that city. They qualify as fakers by virtue of the high prices charged for their instruments, which are sold as historical items: see **Figs. 5a-b**.

One astrolabe from this workshop was purchased in Bombay in the early 1980s by a German sea-captain. He then offered it to the Deutsches Schiffahrtsmuseum in Bremerhaven, who consulted with me as to whether they should acquire it. I told them to have the sea-captain take it back to India and get his money back. This he surely did, for a few months later a Lufthansa pilot brought me the same instrument, which he too had purchased in Bombay. This astrolabe, like the others from the same workshop in New Delhi, which include also European astrolabes, is characterised by the excessive thickness of its back. Hence, these instruments are unduly heavy for their size. Indian fakers have also produced large and fantastic instruments together with "books" consisting of brass plates engraved with illustrations of these instruments: see **Figs. 6a-b**.[12]

The makers have a singularly eclectic taste, and clearly they have been advised by someone who knows the scholarly literature. One piece I have inspected bears a rete in standard Maghribi style, a mater copied from a Yemeni astrolabe (published by myself!—see **XIVa**), an unusual plate copied from an illustration in an 11th-century Central Asian treatise (published by S. H. Nasr),[13] a back with scales found only on Indian Sanskrit astrolabes, and a distinctive alidade copied from one on a Persian astrolabe now in Oxford (not shown on the instrument in **Fig. 5b**).[14] For $5000 you get pieces from five different traditions; not, though, five for the price of one, but rather one for the price of fifty. The "Bombay school" is also producing fake European astrolabes. Some of their productions have reached the leading auction houses in Europe, where, once identified for what they are, they can be offered at appropriate prices as decorative art. But a sale at a Massachussets auction-house in 1991 included four, if not five, fake astrolabes as real instruments, one with a recommended price of US$12,000-18,000; so there is still a good chance for an unlucky tourist to get his money back.

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[12] A substantial photographic archive is in the possession of Christophe Roustan Delatour of Boulogne-sur-Seine, who in 1997 kindly sent me a set of copies.

[13] Nasr, *Islamic Science*, fig. 55 on p. 119.

[14] See the astrolabe of Shams al-Dīn Muḥammad Ṣaffār in *Oxford MHS Bilmeir Supplement Catalogue*, pl. XVIIb (#2505).

Part XIVg

A universal astrolabe from 17th-century Lahore

To Jeremy Collins, in appreciation

DEDICATION,
ACKNOWLEDGEMENTS AND NOTES TO THIS VERSION

This study is dedicated to Jeremy Collins, a man who knows a great deal about mechanical devices and technological wonders from astrolabes to Zeppelins, and much else. As a Director of Christie's and as head of the Department for Scientific Instruments until his retirement in 2001, he was largely responsible for encouraging scholarly investigations of instruments that were in some way in need of clarification, be it for a forthcoming auction, or for an authentication, or for an evaluation. He also used his authority to insist on excellence in what Christie's published in their instrument catalogues.

Jeremy's generosity with photographs and archival material greatly assisted my own work on medieval Islamic and European instruments. I have spent hours looking at instruments in his office. Some merit just a few minutes, others have to be photographed and significant details evaluated in the light of other instruments. A lot of detective work is necessary to produce the kind of detailed descriptions that distinguished Jeremy's catalogues, and he shared in the excitement of all the discoveries that this involved. Furthermore, on some of our joint ventures all over Europe and as far away as New York, we had a lot of fun together.

In 2000 I gave a lecture on medieval astronomical instruments in Nuremberg. As I went into the lecture hall, a man pressed into my hand a plastic bag containing an astrolabe, saying he would contact me at my hotel the next day, and then disappearing. During the lecture, I passed the astrolabe around the audience, but had to apologize that this was not really an astrolabe; indeed, I could tell at first sight that there was something funny about it. The mater, clearly of Eastern Islamic provenance, had *shakkāziyya* markings and was fitted with a spurious decorative rete. The next day I talked with the owner, and, to cut a long story short, the piece was auctioned at Christie's of London in 2001 as two separate lots. Only when writing the description of the mater for the auction catalogue did I realize that the rete missing from it had been auctioned at Christie's in 1995, also described by myself. Both pieces thus passed under the hammer of Jeremy Collins, and, as luck would have it, both were acquired by the same astute London dealer. Thus they are together once again. It is a pleasure to acknowledge my gratitude to Christie's and David Sulzberger of Ahuan Gallery for providing photos.

In this study, I have combined the descriptions of each half of this instrument that I prepared for the respective auction catalogues, modifying them where necessary. The rete was described in *Christie's London 4.10.1995 Catalogue*, pp. 20-21 (lot 61). The mater was featured in *Christie's London 05.04.2001 Catalogue*, pp. 43-45, lot 32. The present study is based on these descriptions, and I do not doubt that it will need some revision after François Charette has finished his contribution to our joint study *The Universal Astrolabe of Ibn al-Sarrāj*, and Roser Puig and Emilia Calvo are further advanced in their new study of the universal astrolabe in al-Andalus and beyond.

A universal astrolabe attributable to Jamāl al-Dīn, a craftsman of 17th-century Lahore

Introductory remarks

The standard astrolabe was invented by Greek astronomers in Antiquity. It was inherited in the 8th century by the Muslims, who, during the next millennium, developed the instrument into a scientific work of art and made all possible improvements and modifications to the standard astrolabe. In particular, astronomers in al-Andalus in the 11th-century invented the universal astrolabe. The universal astrolabe achieves most of the same functions as the standard astrolabe by means of a special rete and a mater with special markings that are independent of terrestrial latitude. The universal astrolabic markings on both components bear the curious name *shakkāziyya* in medieval Arabic (**X-5.2**). The universal astrolabe is no longer an analogue computer like the standard astrolabe, but rather a mathematical device for converting between celestial and terrestrial coordinate systems. The instrument is much more rare than the standard astrolabe. In fact, until recently, not a single simple universal astrolabe, essentially in the form invented in al-Andalus, was known to have survived. What we do have is a much more complicated universal astrolabe made by Ibn al-Sarrāj in Aleppo in 729 H [= 1328/29] (#140), preserved in the Benaki Museum, Athens, which I have discussed in **XIVb-5.1**. Therefore any trace of any other universal astrolabe can be of immense scientific and historical interest.

By a remarkable stroke of fortune, the mater and the rete of a universal astrolabe came together in 2001, each part having been acquired by the same London dealer, David Sulzberger of Ahuan Gallery. The International Instrument Checklist number is #4201. A description follows.

The mater

Brass, occasional silver inlay, outer diameter 18.7 cm, inner diameter 16.8 cm, thickness 0.5 cm. Provenance: In 2000 it was in the possession of a dealer in oriental art at Nuremberg, who told me he had acquired it in Switzerland. Apparently purchased (together with a spurious mater and decorative rete, with which it does not belong—see the note below) in Baghdad some time between 1945 and 1950. Featured in *Christie's London 05.04.2001 Catalogue*, pp. 43-45, lot 32. It is not clear when it became separated from its original rete. Now in the possession of Ahuan Gallery, London.

The throne—see **Fig. 1**—is fairly high and essentially triangular with a series of lobes along each side. The shackle is attached to a hole just below the top of the throne and has a rosette on each side of its base. A circular ring with square cross-section is attached to the shackle. On the front of the throne is engraved in an Indian *naskhī* script the name Jamshīd, presumably an owner. This name is used by Muslims only in Iran and India. The engraving lacks the fluidity of that on the rest of the mater.

The circumferential scale around the front of the mater is divided and labelled clockwise for each 6°, with subdivisions for each 1°. The mater itself is engraved with markings for a universal projection, inlaid in silver. These *shakkāziyya* markings consist of meridians for each 6° and
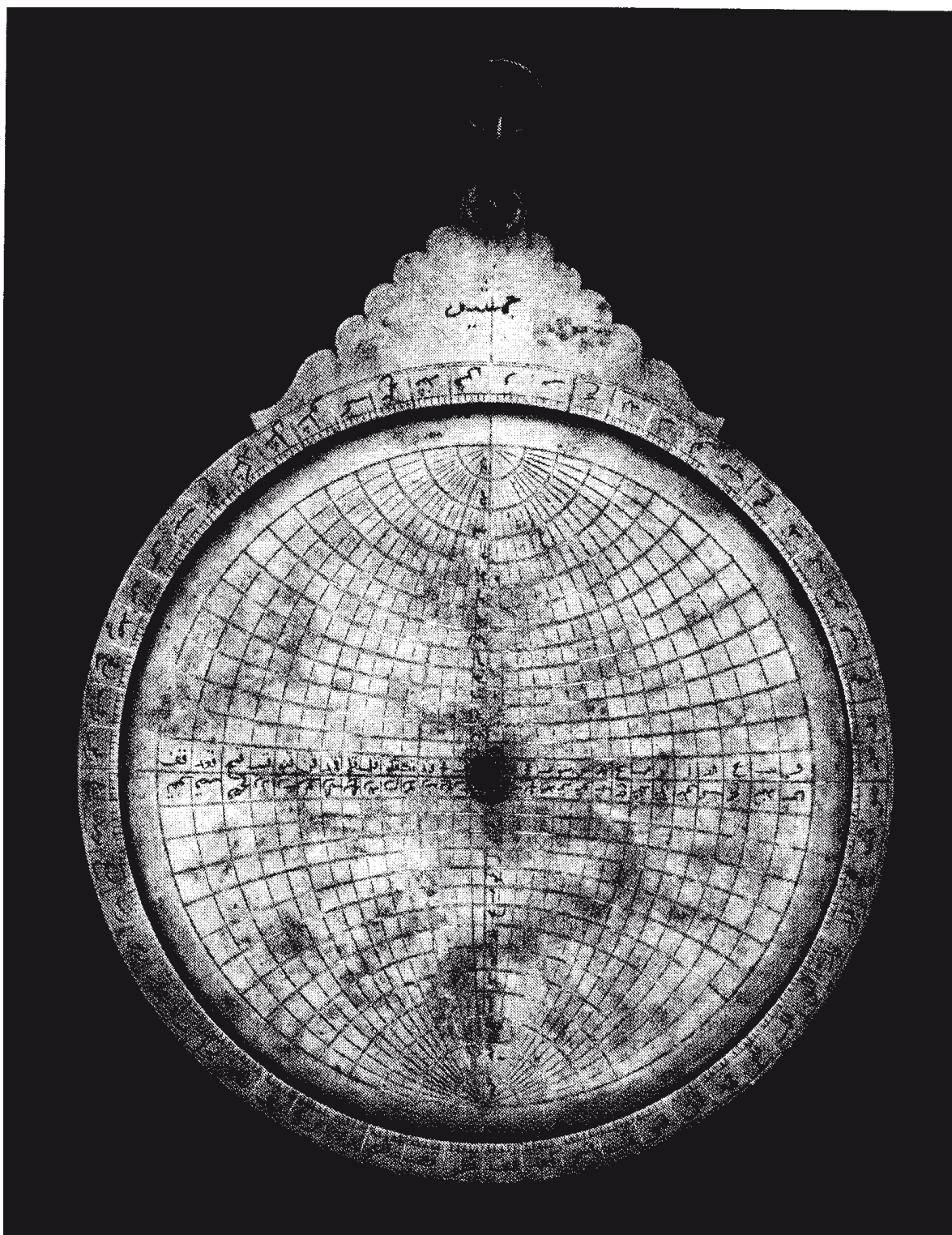
Fig. 1: The front of the mater (#4201). [Courtesy of Christie's, London.]
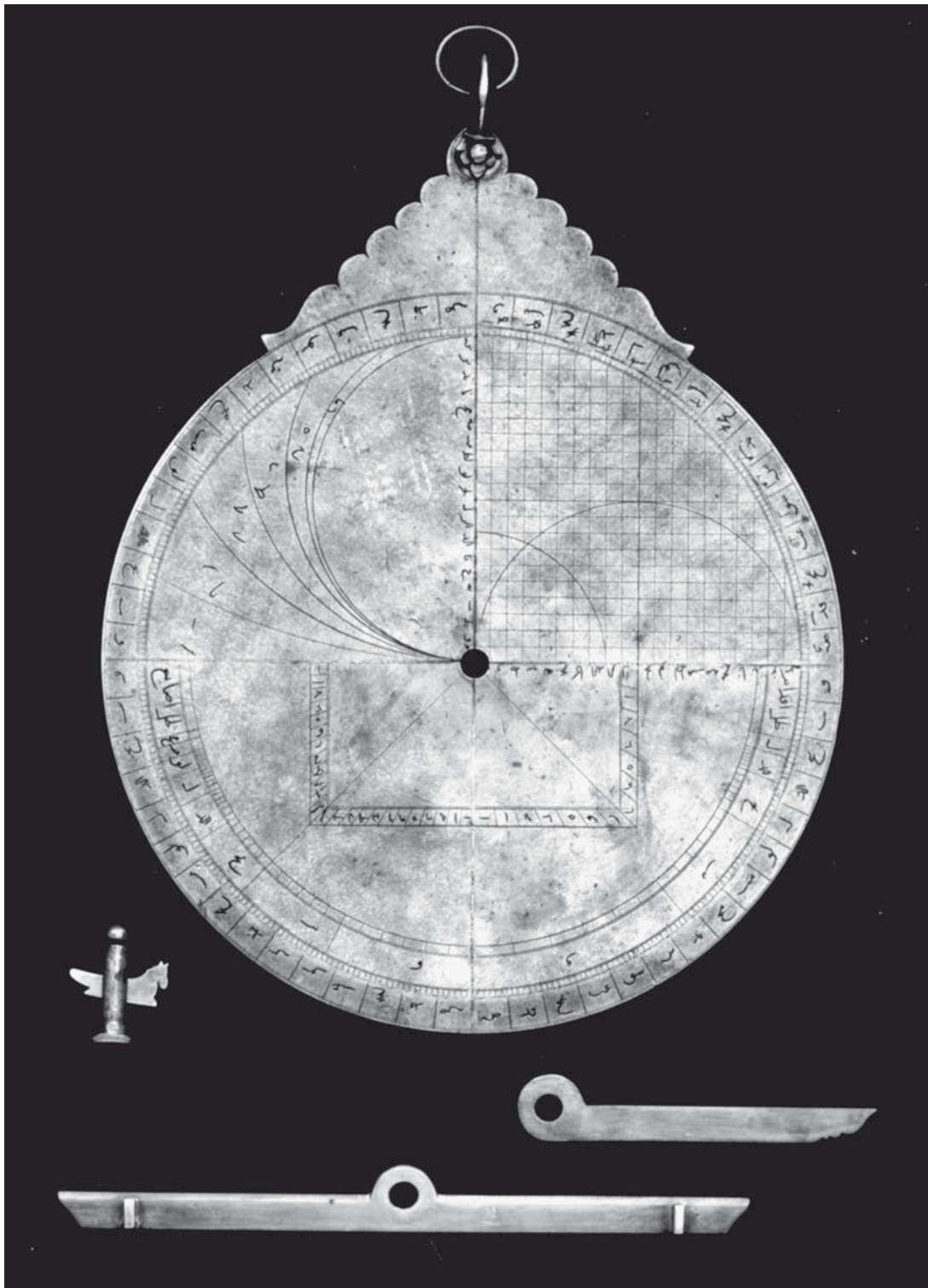
Fig. 2: The back of the mater (#4201). [Courtesy of David Sulzberger, Ahuan Gallery, London.]

declination circles for each 6°. The arguments for the former (from the left: 6°, 12°, ... , 180°, and back: 186°, ... , 360°) are engraved on the horizontal diameter, those for the latter (both up and down from the centre: 6°, 12°, ... 90°) are engraved on the vertical diameter.

On the back—see **Fig. 2**—the outer scales are divided in each quadrant for each 6°, with subdivisions for each 1°. The upper left and two lower quadrants are correctly labelled as altitude scales (with arguments beginning at the horizontal diameter and increasing to 90° at the vertical diameter). In the upper right, the scale has been labelled the wrong way round, but the maker has added the correct labelling in a smaller script. Such corrections of engraving are extremely rare on Islamic instruments, not least because mistakes in engraving are also rare. In the upper left there is a universal horary quadrant, with each curve marked for the seasonal hours it serves: 12/1, 11/2, ... , 7/5, 6/6. In the upper right is a sexagesimal trigonometric quadrant, with equally-spaced horizontals and verticals for each 3 units of the 60-unit scales. The arguments are engraved on each of the radial axes. A semicircle with its diameter on the horizontal axis serves the determination of the sine and cosine from the (corrected) arguments on the upper right scale. A quarter-circle with radius 24 serves the determination of the solar declination. Below the horizontal diameter is a double shadow-square, with divisions for each unit to 12 units on the left and the same to 7 units on the right. Inside the outer scales in the two lower quadrants are additional scales serving the same purpose as the corresponding scales on the shadow-squares. These are labelled appropriately *ẓill-i aṣābiʿ*, “shadow in digits”, and *ẓill-i aqdām*, “shadow in feet”.

The rete

Brass. Diameter: 16.8 cm.
Provenance: unknown. Now in the possession of Ahuan Gallery, London.
Bibliography: *Christie’s London 4.10.1995 Catalogue*, pp. 20-21 (lot 61).

Note: The Iranian mater dated 1156 H [= 1743/44] and decorative rete which were together with this rete when it surfaced in 1994 are featured *ibid*., pp. 22 (lot 62).

The upper half of the rete—see **Fig. 3**—bears *shakkāziyya* markings, carefully and accurately cut out for each 6° of both arguments. The arguments are labelled on the horizontal diameter and on the circumference. The horizontal diameter is also marked for the signs of the ecliptic, starting with Aries at the left of centre and running |←• then |→•→| then •←| .

The lower half bears astrolabic markings, including an arc of a circle for the ecliptic (with the southern signs superposed on the northern ones) with labelled divisions for each 6° within each sign. The signs start on the left with Aries and Libra. On the astrolabe of Ibn al-Sarrāj they start on the left with Aries and Virgo. (The arrangement is arbitrary.)

In the lower half there is also a set of rather crudely-fashioned star-pointers for 11 stars, six of which are on three double-headed pointers, and two of which look distinctly unfinished. The ensemble is surrounded by a rather broad circular frame, on the upper half of which are marked the arguments for one family of circles on the grid.

The pointers serve the following 11 stars (two unnamed, marked with asterisks below), ordered counter-clockwise from the vernal equinox on the left, and marked N and S to differentiate between
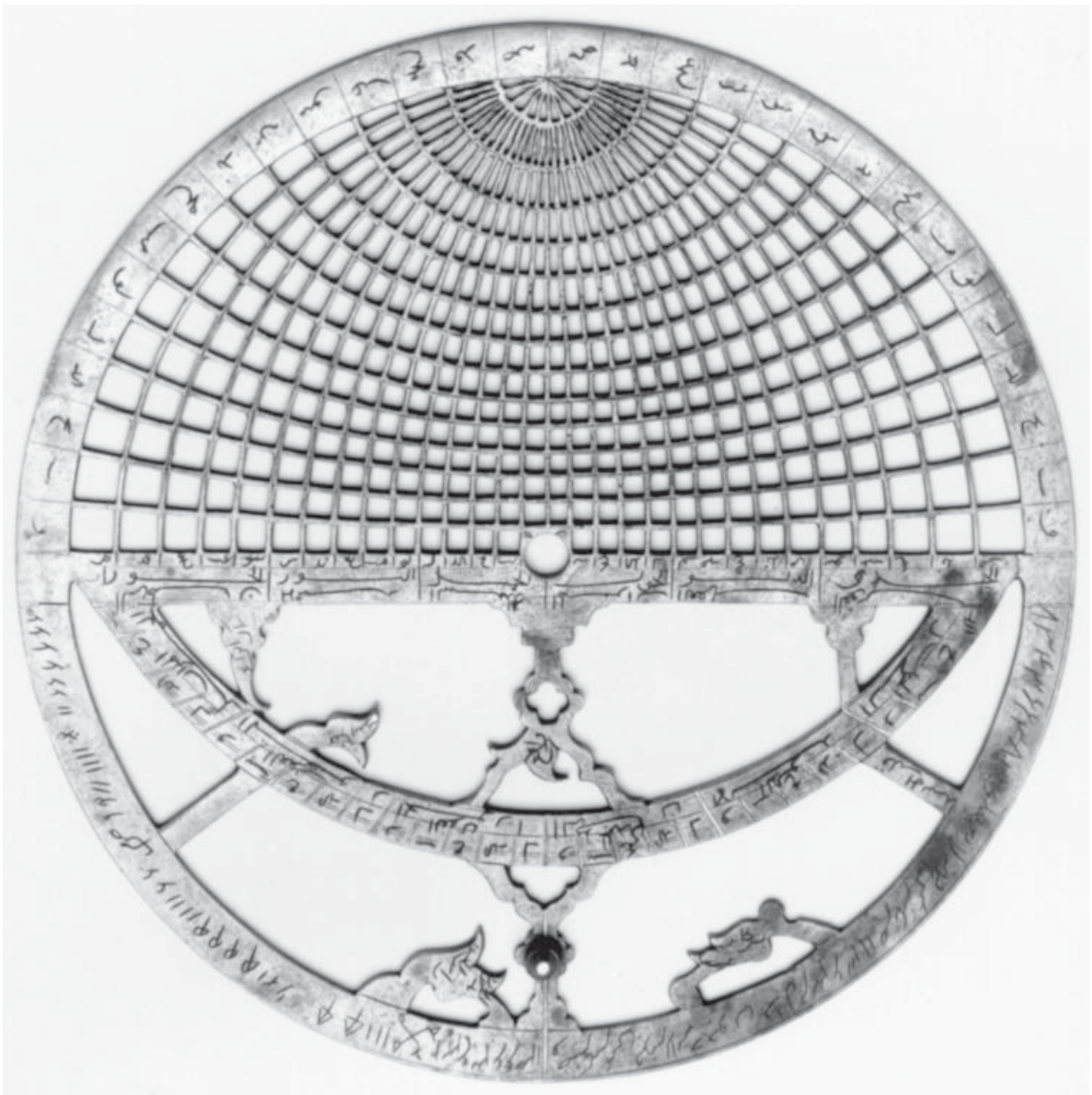
Fig. 3: The rete (#4201). [Courtesy of Christie's, London.]

those achieved by a stereographic projection from the northern celestial pole and the standard projection from the southern one:

simāk al-rāmiḥ	α Boo	N	*wāqiʿ*	α Lyr	N
al-ghūl	β Per	S	*ghumayṣāʾ*	α CMi	S
[*fakka*] (written *falaka*)	α CrB	N	*nasr al-ṭāʾir*	α Aql	N
[*al-ʿayyūq*]	α Aur	S	*qalb al-asad*	α Leo	S
raʾs al-hawwāʾ	α Oph	N	[*fam al-hūt* (?)]	α PiA	N
yad al-jawzāʾ	α Ori	S			

The positions of all but the last two star-pointers are extremely accurate for *ca*. 1650.[1] The penultimate "pointer", named for *qalb al-asad*, bears no marker for the star, but the place where its left-hand edge meets the ecliptic is indeed the position of α Leonis (Regulus) for *ca*. 1650. The last "pointer" likewise bears no marker but also no name; it may have been intended for the star α Piscis Austrini (Fomalhaut), which is featured on both Ibn al-Sarrāj's astrolabe (see **Figs. X-5.2.4** and **XIVb-5.1a**) and on the rete illustrated in Najm al-Dīn's book on instrumentation (see **Fig. 4**). (The fact that the right-hand edge of the pointer, which is not marked in any way, passes through the position of δ Aqu (Scheat) for *ca*. 1650 is probably coincidental, since this star-pointer, found mainly on Indian astrolabes, would not have been featured on any astrolabe by Ibn al-Sarrāj.) What is remarkable is that the maker was able to identify the proper star-positions; the positions for *ca*. 1325, the time of Ibn al-Sarrāj, would be noticeably different. There are two possibilities: either the rete was made *ca*. 1650 or it is a later copy of one made then. The satisfactory execution and also the calligraphy argue for the former possibility, which is confirmed by comparison with other pieces by the Lahore school (see below). The main evidence for the latter—namely, that the maker refrained from marking two of the star-names, did not know how to write the star-name *fakka*, and did not finish two of the star-pointers—can be explained away by the fact that the maker was not well-versed in Arabic. This, however, instead of requiring a late provenance, brings us back to the Lahore school (see below).

The lower half of the circular grid originally bore no markings. The available space has been filled by a later (19th- or early-20th-century) hand with inscriptions more appropriate for a fake astrolabe: there are a series of numbers in Arabic numeral notation and there are two inscriptions that contain word-plays on verses from the *Qurʾān* (*cf*., for example, XXXVI, 67 and 68). They appear to read: "*w-ṣ-r-x-k-m ʿ-m-y* (?) *fa-hum lā yarjiʿūna / yurjaʿūna w ʾ l m* (??)" and "*ṣ-r-x-k-m ṣ-r-x-k-m ʿ-m-y* (?) *fa-hum lā yaʿqilūna*" (where *x* is an unpointed carrier that can be read *b/t/th/n/y*). Neither is immediately legible or comprehensible.

[1] Stautz, *Mathematisch-astronomische Darstellungen auf mittelalterlichen Instrumenten*, pp. 66 and 69-70 (SA9) and fig. 3.6h on p. 214.

Fig. 4: The rete of a universal astrolabe as depicted in the treatise of Najm al-Dīn al-Miṣrī (Cairo, *ca*. 1325). The universal markings are from a different half of a *shakkāziyya*, but the principle is the same. (The text on this page, dealing with a universal astrolabe of with Ibn Bāṣo-type markings, is not related to this rete, as noted in the margin.) For a detailed investigation of this illustration, together with a comparison with the retes of ʿAlī ibn Khalaf and Ibn al-Sarrāj, see now Charette, *Mamluk Instrumentation*, pp. 103-108. [From MS Dublin CB 102, fol. 81v, courtesy of the Chester Beatty Library.]
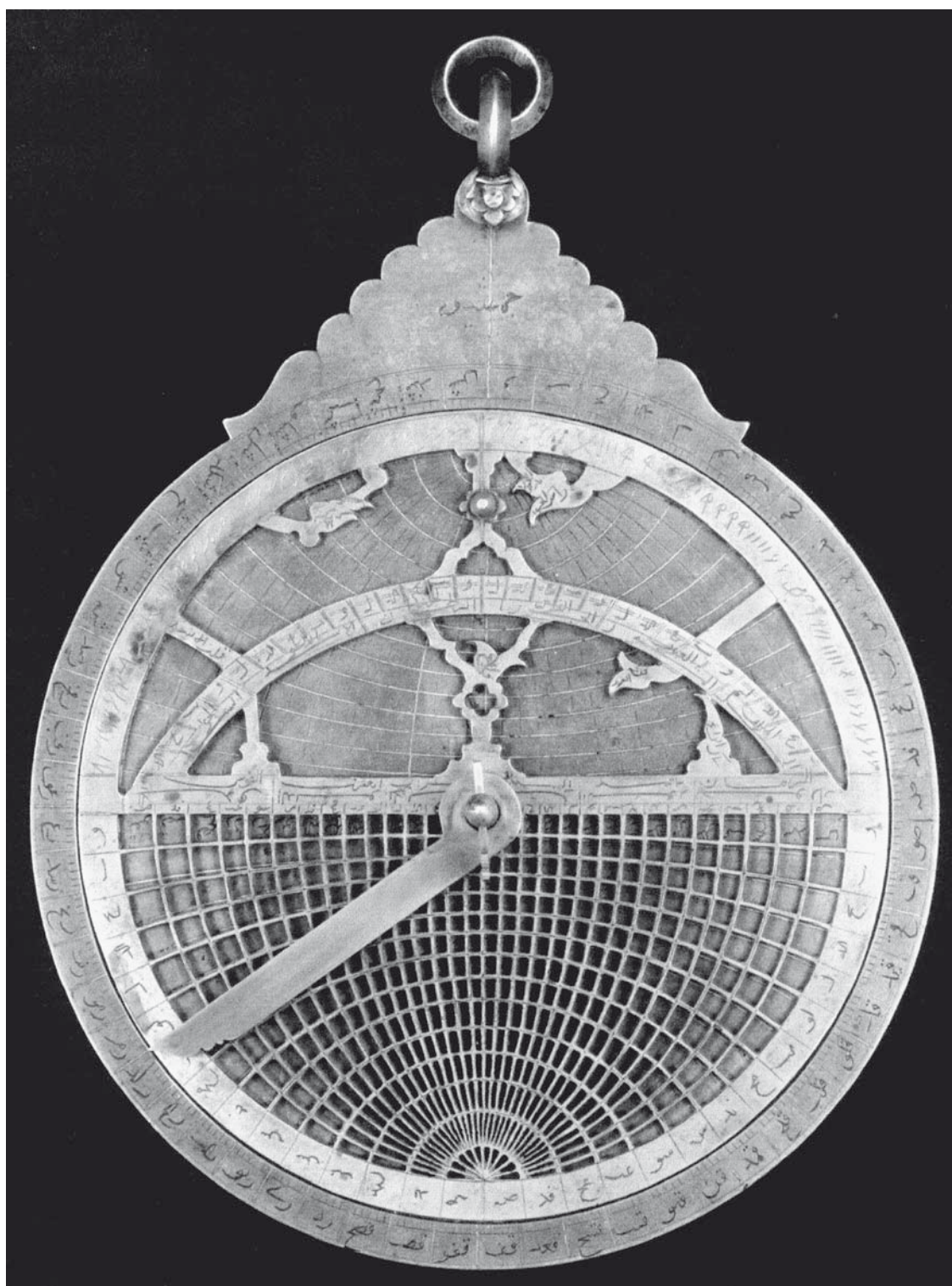
Fig. 5: The sole surviving universal astrolabe of the simple variety (#4201). [Courtesy of David Sulzberger, Ahuan Gallery, London.]

The combination of mater and rete

The rete fits perfectly in the mater! Our universal astrolabe—see **Fig. 5—**is clearly Indian,[2] possibly Delhi, possibly Lahore. In favour of a Delhi provenance is the fact that most of the astrolabes in the Archaeological Museum in Delhi today are unsigned.[3] The only argument against a Lahore provenance is the fact that most Lahore instruments are signed and usually dated as well. However, various aspects of the calligraphy, which is a relaxed and neither particularly distinctive nor elegant *naskhī* script, point to 17th-century Lahore, where there was a very active school of astrolabists associated at first with the royal court (see **XIVf**). The hand in fact resembles very closely that of Muḥammad Muqīm, the grandson of the founder of the school, Allāh-dād or Ilāh-dād, or that of Muḥammad Muqīm's son, Jamāl al-Dīn. Muḥammad Muqim is known by one globe and about 30 astrolabes, of which one in particular, dated 1634,[4] attests to his extraordinary skills in marking unusual astrolabic plates. Jamāl al-Dīn is known by two astrolabes, of which one, dated 1077 H [= 1666/67] (#4143),[5] is the only known Islamic astrolabe bearing a world-map engraved in the mater.[6] The association with Jamāl al-Dīn is strengthened by the fact that on the new rete the star-name *fakka* is incorrectly written as *falaka*, a mistake also found on the rete of the above-mentioned 1666 instrument: see **Fig. XIVf-3a**.

Proof that Jamāl al-Dīn did not copy the rete of the *Athens* instrument of Ibn al-Sarrāj is provided by (a) the existence of a quatrefoil on the rete; and (b) the second double zodiacal scale on the horizontal diameter. Neither of these features occurs on the Athens piece. As far as we know, the quatrefoil was first put on Islamic astrolabes in the 10th century. It features, for example, on the magnificent astrolabe of al-Khujandī (#111—see **XIIIc-9**), dated 374 H [984/85], and various later instruments in the same tradition: see **XVII**. It is reasonable to suppose that this newly-identified rete was copied from one by Ibn al-Sarrāj, otherwise unknown to us, which also featured a quatrefoil. The ecliptic scale on the horizontal diameter serves operations in which the grid is used to represent ecliptic-based (as opposed to equator- or horizon-based) coordinates, and reflects the kind of ingenuity to be associated with Ibn al-Sarrāj.

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[2] The possibility that the rete was made in Ottoman Turkey or in Safavid Iran may be dismissed outright on calligraphic and stylistic grounds. Each of the few astrolabes made in al-ʿIrāq between *ca*. 1500 and *ca*. 1900 is problematic in one way or another (incompetent astronomical markings or inscriptions, or both). Furthermore, not a single astrolabe of any consequence is known from either Syria or Egypt from the period after *ca*. 1500. Therefore we must look elsewhere for the provenance of this piece.

[3] See Kaye, "Delhi Astrolabes".

[4] #71—Museum of the History of Science, Oxford—see Gunther, *Astrolabes*, I, pp. 191-197.

[5] #4143—now in the Science Museum, London—see my description in *Christie's New York 31.10.1985 Catalogue*, pp. 94-95 (lot. 331). See now **XIVf-4**.

[6] See now King, *Mecca-Centred World-Maps*, pp. 95-96.

Part XV

An astrolabe from medieval Spain with inscriptions in Hebrew, Arabic and Latin

To Julio Samsó
and his colleagues in Barcelona,
Emilia Calvo, Mercè Comes, Miquel Forcada, Roser Puig,
and Mònica Rius (*ṣāḥibat al-qibla*)

DEDICATION,
ACKNOWLEDGEMENTS AND NOTES TO THIS VERSION

This study is dedicated to the members of the Barcelona school under my good friend Julio Samsó. They have continued the tradition of first-class scholarship on the history of the mathematical sciences in medieval al-Andalus and al-Maghrib initiated by José María Millàs Vallicrosa (1897-1970) and his successor Juan Ginès Vernet (1923-).* Their scholarship has embraced all aspects of these sciences from the simple astronomy and astrology found in survivals of earlier Visigothic sources to the highly complicated mathematical astronomy and astrology found in later Islamic writings. It has also paid due attention to astronomical instrumentation, which is not always the case with historians of science. It has further included the transmission of Western Islamic sources to medieval Europe by Hebrew and Latin intermediaries, whereas many historians of medieval science have not been familiar with the Arabic sources of such materials. Without wishing to delimit too finely their individual contributions to our subject, anyone who wants to know anything about the general history of astronomy in al-Andalus must consult the works of Julio Samsó; for the universal instruments devised by Andalusī scholars, Roser Puig and Emilia Calvo; for equatoria and mathematical geography, Mercè Comes; for folk astronomy, Miquel Forcada, and, last but by no means least, for the qibla and mosque orientations in al-Andalus and al-Maghrib, a topic especially close to my heart, Mònica Rius. The interested reader may consult the website ub.es/arab/llibrevs/llibres.htm. For the present it must suffice to register my gratitude at having been able to collaborate with each of these colleagues over many years.

This study first appeared as "An astrolabe from 14th-century Christian Spain with inscriptions in Latin, Hebrew and Arabic—A unique testimonial to an intercultural encounter", in *Suhayl—Journal for the History of the Exact and Natural Sciences in Islamic Civilisation* (Barcelona) 3 (2002-03), pp. 9-156. I am grateful to Mònica Rius for all the editorial work she put in to that version, and to Julio Samsó for permission to reprint the article so soon after it was published in the new Barcelona journal.

I also wish to acknowledge the generosity of the curators of the various museums and the owners of private collections in which the instruments discussed in this study are preserved. For illustrations I am indebted first and foremost to Jeremy Collins, formerly of Christie's, London, who provided photographs of the Spanish astrolabe. Other photos were kindly made available by the The Adler Planetarium, Chicago; the Museum of the History of Science at Oxford, and the Bibliothèque Nationale de France, Paris. During the course of the research for this study, I had the pleasure and privilege of using the facilities of the Biblioteca Nacional in Madrid and the Widener Library at Harvard University. Grateful thanks are also due to various friends and colleagues for

* See the tributes in *Millás-Vallicrosa Festschrift* and *Vernet Festschrift*. A recent tribute to Julio Samsó and the new Barcelona school by Charles Burnett is in *Bulletin of Hispanic Studies* 74 (1997), pp. 123-124.

their assistance on various aspects of this study and for their encouragement: Maravillas Aguiar Aguilar (La Laguna, Tenerife), Guy Beaujouan (Paris), François Charette (Frankfurt *thumma* Cambridge, Mass.), Karine Chemla (Paris), Benno van Dalen (Frankfurt), Koenraad van Cleempoel (Antwerp), Federico Corriente (Saragossa), Reinhard Glasemann (Frankfurt), Martin Hellmann (Heidelberg), Peter Sjord van Koninksveld (Leiden), Paul Kunitzsch (Munich), Y. Tzvi Langermann (Jerusalem), Martina Müller-Wiener (Bonn), Julio Samsó (Barcelona), Eleanor Sims and Ernst Grube (London), Burkhard Stautz (Huenfelden), Anthony Turner (Le Mesnil-le-Roy), Annette Weber and Johannes Wachten (Jüdisches Museum, Frankfurt), and Juan Zozaya (Madrid). Mine alone is the responsibility for any remaining errors and misinterpretations.

CONTENTS

1 Introduction

> "The work has swollen by degrees until that which I had originally intended as a mere description of a single instrument may now perhaps have some pretension to be considered as a monograph of the Planispheric Astrolabe. I can scarcely hope to have attained so much, but I believe that I have resumed all that has appeared on the subject, and have added something from original sources. Many, no doubt, will accuse me of having bestowed too much labour on what they deem to be almost if not wholly unworthy of notice, and at the best will class my work amongst what are called "learned trifles". If so, I shall not complain, for learned trifles, however apparently trifling, are never devoid of utility; and the importance of a strict attention to details in the history, whether of nations or of sciences, is felt and acknowledged by all who look deeper than the surface. Should I have offered materials even for a page in a future history of Astronomical Science, I shall not have wasted my time." William H. Morley, *The Astrolabe of Shāh Ḥusayn* (1856), p. ii.

A medieval European astrolabe with inscriptions in both Latin, Hebrew and Arabic which has recently come to light—see **Figs. 1-9**—is unique for a variety of reasons.[1] The few Islamic astrolabes that fell into European hands already in the Middle Ages often bear Hebrew or Latin additions to the original Arabic inscriptions. But not a single medieval European astrolabe other than this one bears Arabic inscriptions from before *ca*. 1800. In fact, it bears a set of original Latin inscriptions completed by a set of Arabic ones, and it has an additional layer of markings in Hebrew characters. The last-mentioned appear to predate the others, having been added during the construction and hence prior to the main engraving. In any case, this piece is not the work of a single craftsman, but of at least two and possibly three or even more.

Of all the regions of Christian Europe where astronomy was cultivated during the Middle Ages, Spain has the least number of surviving instruments. This is rather ironical not least because it was in the Iberian Peninsula that Europeans first came into contact with astronomy in general and the astrolabe in particular.[2] Only five medieval European astrolabes can be securely associated with the Iberian Peninsula, this one and four others from Catalonia—details are given below.[3] Each is quite different from the other in design, and each one underlines

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[1] The astrolabe has changed hands several times in the last few years and now belongs to an unidentified private collector. A detailed description by this author, condensed from the present study, is in *Christie's 15.4.1999 Catalogue*, pp. 98-107, lot 52 (the illustration of the Hebrew markings on p. 102 was printed back to front). A less detailed description by this author is in *Sotheby's 18.10.2001 Catalogue*, pp. 110-113, lot 111. The piece had become available for study after it was auctioned in 1998 at the Hôtel des Ventes Anticthermal in Nancy. It had been acquired by the vendor as part of a large estate, he being a distant relative of the deceased, who has not been identified. A preliminary description of the instrument prepared for the auction in Nancy by Anthony J. Turner with assistance from Emilie Savage-Smith is listed under Turner as "Astrolabe exceptionel" / "Exceptional Astrolabe". This overlooks some of the most historically-important features and contains numerous misinterpretations, especially about the provenance (see nn. 46, 49, 187 and 286).

[2] The most original research on the complicated story of the mathematical sciences in Muslim and Christian Spain is collected in Millás Vallicrosa, *Estudios*, I-II; Vernet, *Estudios*, I-II; and *idem*, ed., *Estudios*, I-II; Samsó, *Ciencias en al-Andalus*, *idem*, *Studies*; and Vernet & Samsó, "Science in Andalusia", as well as various other works by the same authors and other members of the Barcelona school, including *Santa Cruz 1985 Exhibition Catalogue* and *Madrid MAN 1992 Exhibition Catalogue*. Alas, none of these works contains any materials relevant to the astrolabe under discussion.

[3] See already Gunther, *Astrolabes*, II, p. 305, on the dearth of astronomical instruments surviving from this milieu. Even the *Santa Cruz 1985 Exhibition Catalogue*, entitled *Instrumentos astronómicos en la España medieval*, did not feature a single medieval European instrument from Spain. See also n. 288 below.

Fig. 1: The front of the 14th-century Spanish astrolabe (#4560). [The photos in Figs. 1, 2, 4a, 5, 6a-b, 7a and 7d are courtesy of Christie's of London. The details of the astrolabe in the other illustrations are by the author, courtesy of a former owner.]

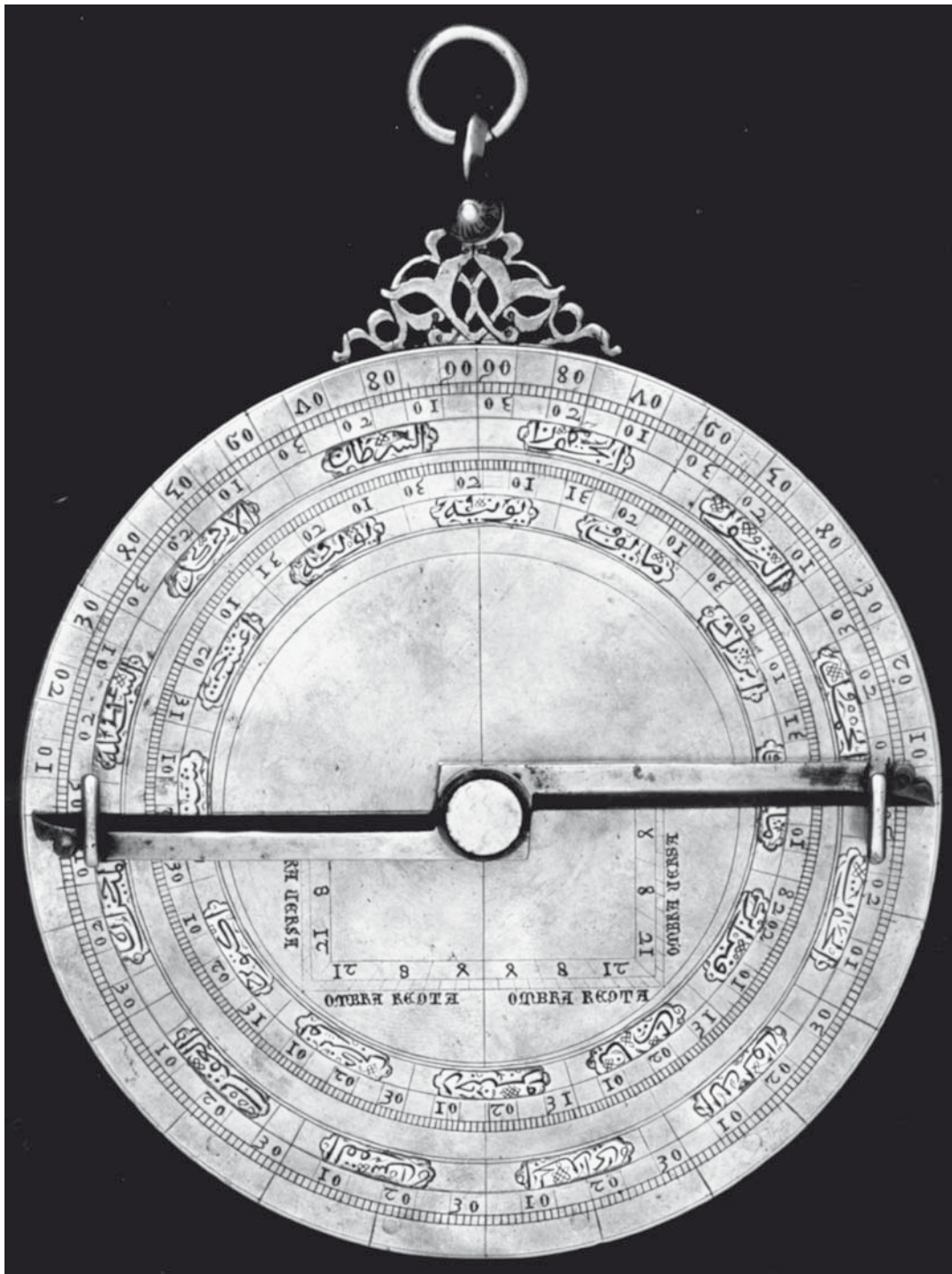
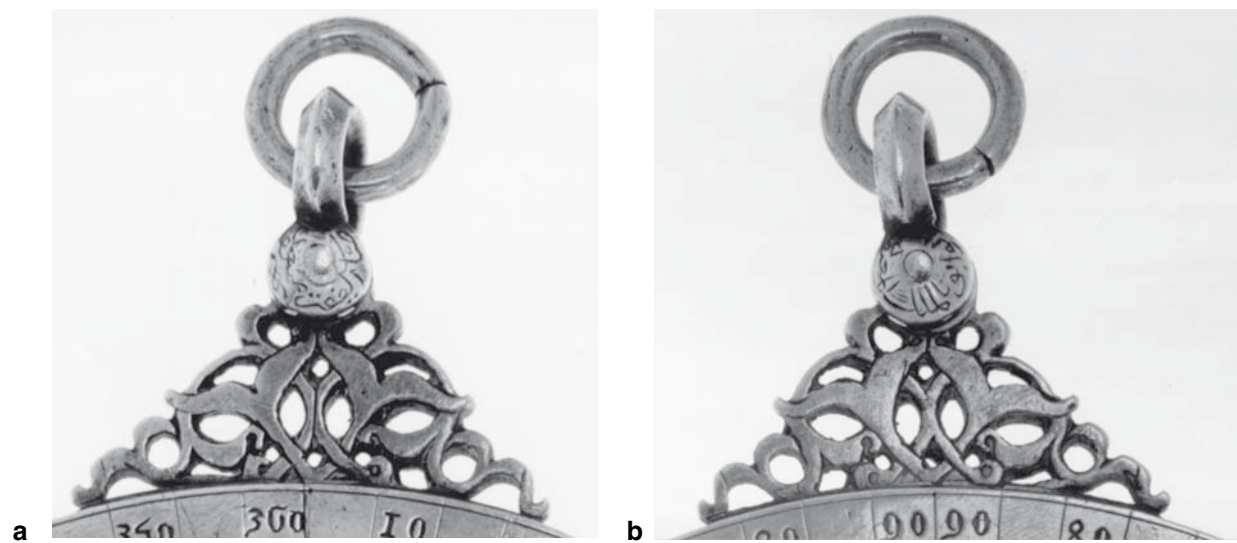



Fig. 2: The back of the astrolabe (#4560).

Figs. 3a-b: The inscriptions by Masʿūd on the front and back of the boss of the shackle.

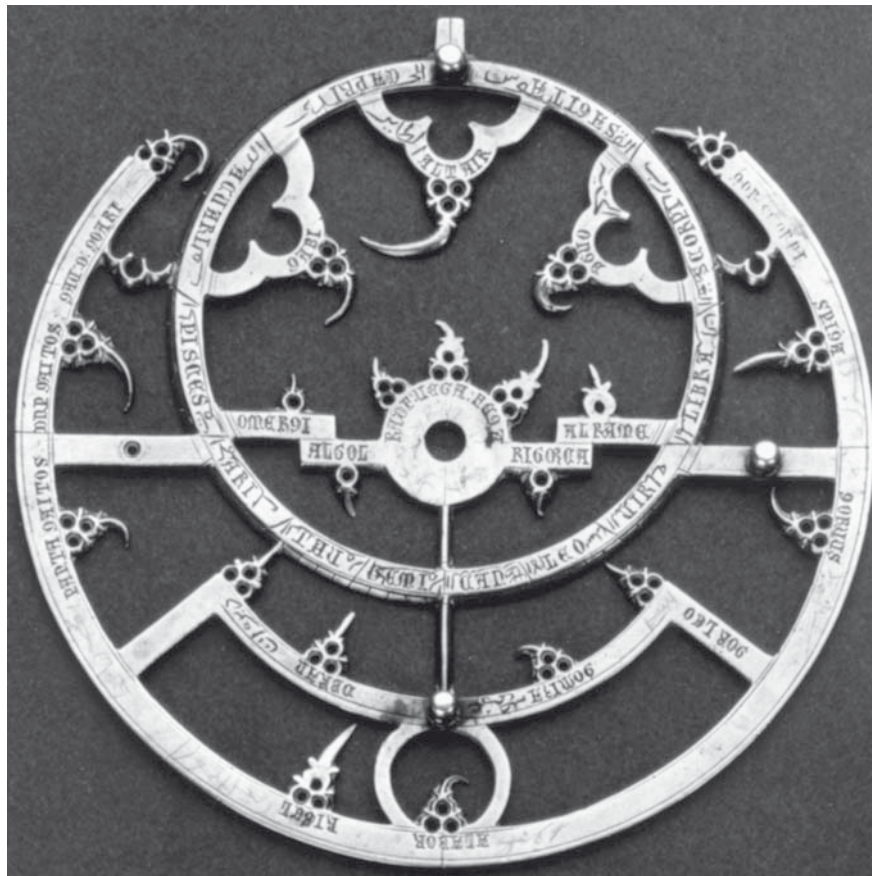



Fig. 4a: The rete.

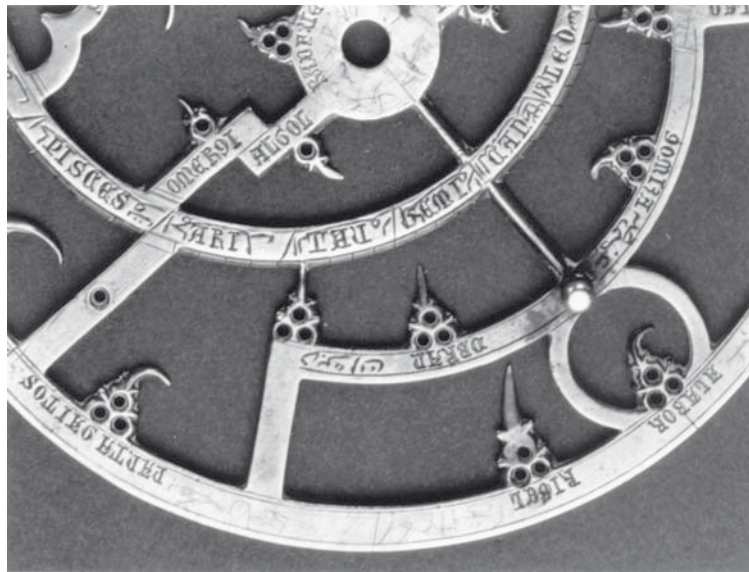



Fig. 4b: Part of the rete, with the star-pointer for Aldebaran near the middle, the name being engraved in abbreviated Latin and Spanish Arabic. Note the additional Arabic names for the zodiacal signs, and the crudely-scratched Arabic names for some of the stars.

Fig. 5: The inside of the mater, showing the impressions of the cartouches on the back; the back of the rete; and the top and bottom of the alidade together with what is possibly one of the two oldest surviving screws from medieval Europe.

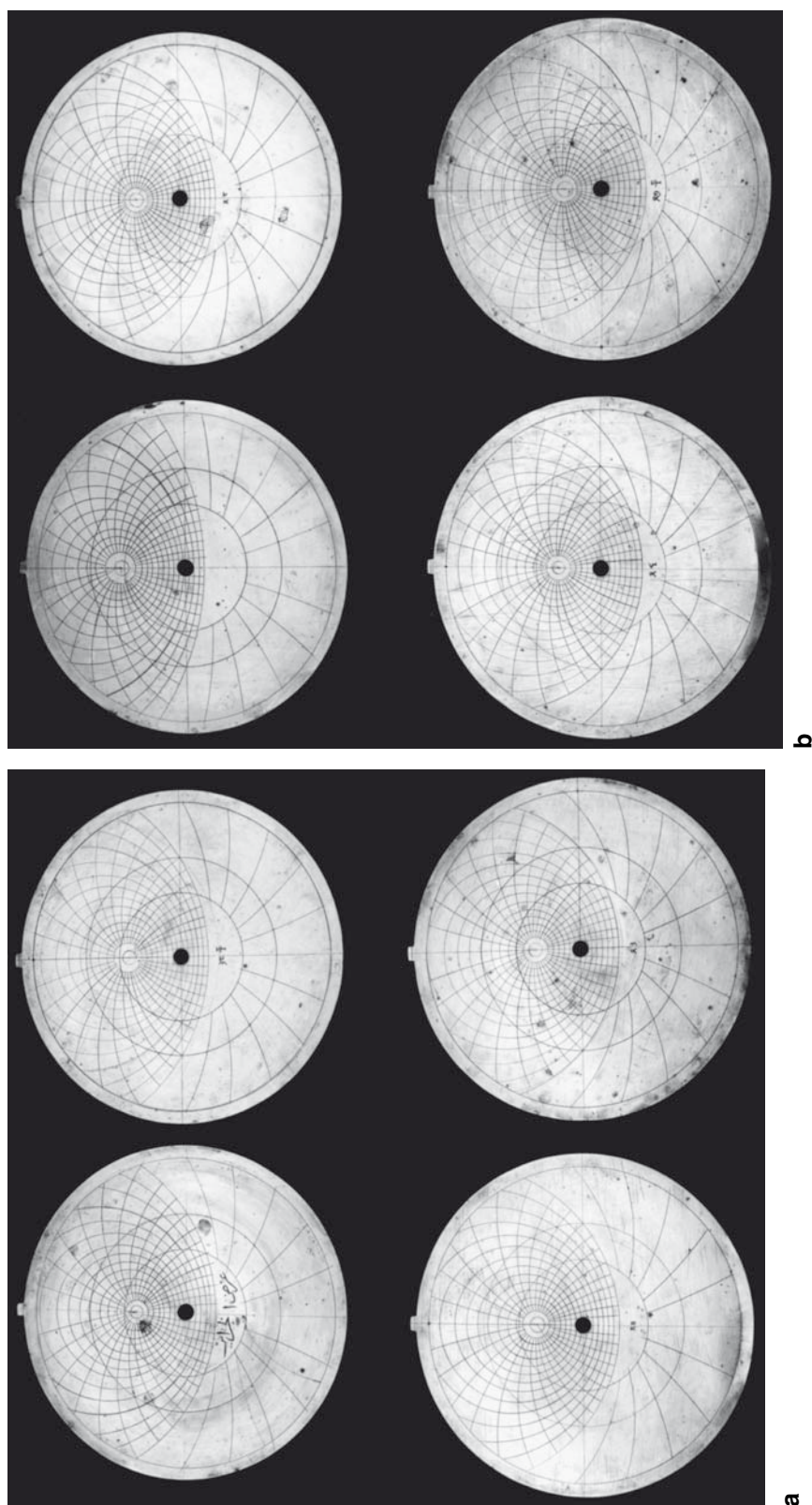



Fig. 6a: The plates for the latitude of Algiers (see also **Fig. 7d**), $32^1/_2$°, 43° and 40°.
Fig. 6b: The plates for [Mecca], 42°, $49^1/_2$° (see also **Fig. 7a**), and 45°.

how little we know and, without the appearance of new sources such as the astrolabe under discussion, can ever hope to know about medieval astrolabes from the Iberian Peninsula, which are the key to understanding the introduction of the astrolabe to Europe. Yet we do know, from manuscript sources as well from one surviving 10th-century astrolabe, that Europeans in Spain started making astrolabes with inscriptions in Latin already in that century. Presumably, dozens were actually made there during the Christian Middle Ages. Many more Islamic instruments survive from al-Andalus, that is, that part of Spain which at any given time was in Muslim hands, including some 20-odd from the 11th century (not all complete) and over 50 from the 13th-15th centuries (none from the 12th century). Astronomical instruments with inscriptions in Hebrew are rare indeed, in spite of the highly significant role of the Jews in the transmission of scientific knowledge to the West.[4] Only one medieval astrolabe from al-Andalus or the Maghrib with inscriptions in Hebrew characters survives—see below for details.

The instrument, in spite of the Arabic inscriptions, qualifies as a European astrolabe rather than an Islamic one. There is ample evidence that it was made in Central or Northern Spain (Toledo or Saragossa?) in the 14th century, and that it hails from a milieu in which Christians collaborated fruitfully with Muslims and Jews. This *convivencia* was not always voluntary and not always amicable.[5] Both Toledo and Saragossa had, however, been the scenes of serious scientific activity for several centuries.[6] Toledo had witnessed the ingenious Muslim astronomer Ibn al-Zarqālluh (known in the Latin West as Azarquiel) and the compilation of the hodge-podge of astronomical tables known as the *Toledan Tables*, both in the 11th century, then the capture by the Christians in 1085, followed by the vigorous activities at the court of Alfonso X "el Sabio" in the 13th century. Saragossa had witnessed the brilliant mathematical activities of the Muslim King al-Muʾtaman ibn Hūd in the 11th century,[7] but fell to the Christians in 1110. In the 14th century Ptolemy's *Almagest*, which represented the culmination of Greek astronomical knowledge, was still being copied in Arabic in that city.[8] Jewish scholars were associated with the astronomical activities at the court of Alfonso X, and with the astronomical, astrological and cartographic interests of Pedro IV (1336-87), ruler of the Crown of Aragon. Also, it is well established that Jews were involved in the metal-trade in Spain in the Middle Ages,[9] and no less that Jewish craftsmen were involved in instrument construction in Spain during the Middle Ages.[10]

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[4] A recent survey of Jewish astronomical activity in Spain is Goldstein, "Astronomy of Spanish Jews". Some of the most reliable research on Jewish contributions, rather than their role as transmitters, is collected in Langermann, *Studies*. On instrument texts in Hebrew, albeit from Sicily, see Goldstein, "Astronomical Instruments in Hebrew". Glick, "Jewish Contribution to Science in Medieval Spain", is particularly weak on instruments—see n. 288 below.

[5] On this see *New York JM 1992 Exhibition Catalogue*, entitled *Convivencia ...* , especially the introductory remarks by Thomas F. Glick on pp. 1-9.

[6] See Samsó, "Exact Sciences in Al-Andalus", for a recent overview of this activity.

[7] See Hogendijk, "al-Muʾtaman ibn Hūd".

[8] See also Kunitzsch, *Sternkatalog des Almagest*, I, pp. 6-7, *idem*, "Ptolemy in al-Andalus", pp. 148-149, and *idem*, "*Almagest* Manuscript", on a Judaeo-Arabic copy of the *Almagest* partly copied in Calatayud in 1380 with the rest completed in the same city in 1475, and an Arabic copy which came into the possession of a Jewish scholar in Saragossa near the end of the 15th century.

[9] Article "Metals and Mining", in *EJ*, especially p. 1442, where it is stated:

"Many Jewish craftsmen and artisans were engaged in the metal industry in Christian Spain. In 1365 three Jewish smithies are mentioned in Toledo, and there were Jewish workshops in Avila, Valladolid, Valdeolivals
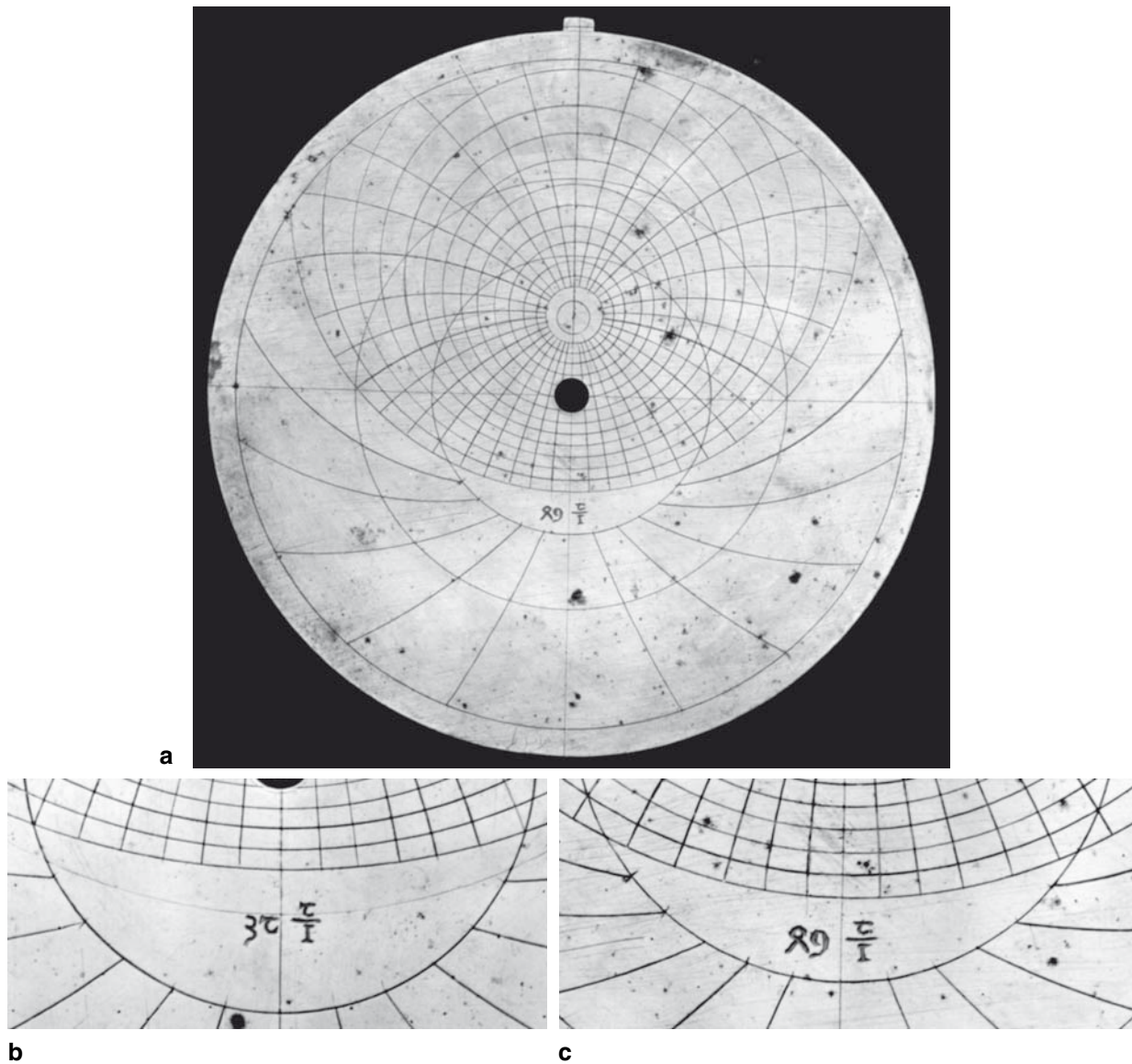
Fig. 7a: The plate for latitude $49^1/_2°$.
Figs. 7b-c: The latitudes $32^1/_2°$ and $49^1/_2°$ (for Jerusalem and Reims) represented with the standard medieval forms of the Arabic numerals but for the '2', which is inverted, and the bar fraction for one-half, which is also inverted.

near Cuenca, and Talavera de la Reina; a Jewish tinsmith, Solomon (Çuleman) b. Abraham Toledano of Avila, is mentioned in a document of 1375; at the close of the 14th century, Jewish smiths were called upon to repair the copper fountain of Burgos. Before 1391 many Jewish smiths, engravers, and goldsmiths lived in Barcelona. From a Saragossa register of 1401 we learn that there were many Jewish engravers and artisans in copper and iron. The local engraver's synagogue was used for the meeting of the community administration."
No source is given for this information, and it is not, as one might expect, Wischnitzer, *Jewish Crafts*. See *ibid*., pp. 92-113, on Jewish crafts and guilds in medieval Spain. In Shatzmiller, "Professions in Muslim Spain", based on a medieval Maghribi source, virtually every working-class profession is mentioned but, alas, not instrument-making (perhaps because these people were professionals).

[10] See Mackay, "Jews in Spain", p. 40, for a brief overview, and also Vielliard, "Horlogers catalans", pp. 166-167.
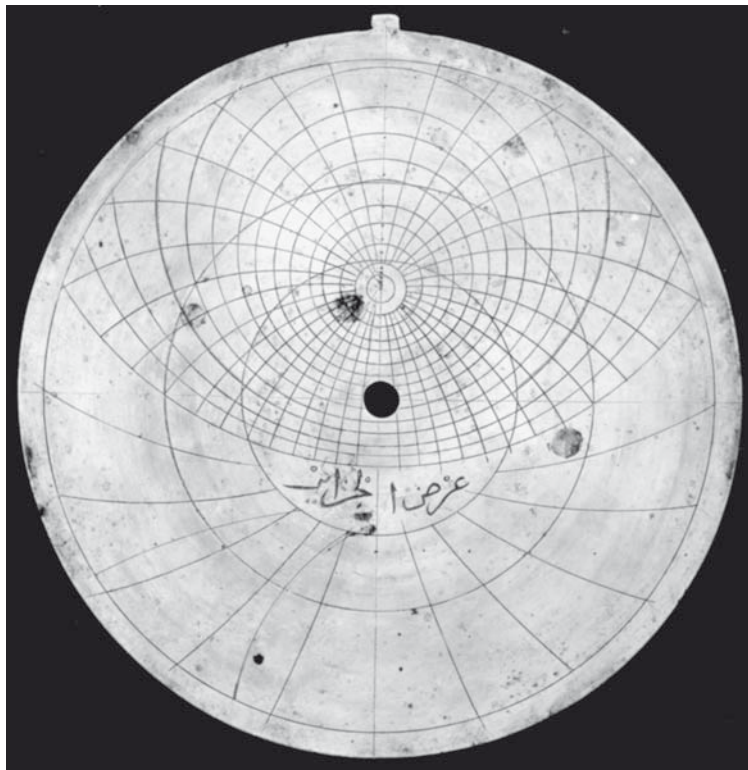
Fig. 7d: The additional plate for Algiers.

Figs. 8a-b: The latitudes 42° and 49;30° scratched in Hebrew alphanumerical notation on two of the plates.

Figs. 9a-b: On the left, the cartouche for December, with the month-name correctly engraved, along with the *feria* '6' and a complete endless knot. On the right, the cartouche for Virgo, showing the name *al-sunbula* incorrectly engraved (without the '*n*'), a *hamza* (?), an *a*-vowel and an *i*-vowel, and a partial endless knot with additional floral strands.

Whoever started this instrument gave up his task before it was completed. Death or some other personal catastrophe might have forced this. The one cause of death and disaster that took everyone by surprise in the mid 14th century was the Black Death.[11] Somehow, the instrument then came into the hands of a Muslim Arab named Masʿūd, who finished it. The Muslims living under Christian domination, the *mudéjar*s,[12] were constantly being urged by their co-religionists in the Naṣrid Kingdom of Granada (all that was left of "al-Andalus") and the Maghrib to emigrate to the Islamic world. Perhaps Masʿūd was a prisoner of the Christians in Spain, but he was no doubt a man of some standing, not least because he was skilled in the craft of astrolabe-making and in the basics of applied scientific knowledge, and no less because he became the first owner. There is evidence that Masʿūd made his contributions to the astrolabe in Spain but he clearly intended to take the instrument to Algiers, for the Arabic inscriptions specifically mention that city. If the piece did go to Algiers, then it returned to Europe, this time to Northern or Eastern France, by the 16th century, as evidenced by yet another layer of inscriptions. If it was not taken to Algiers, then possibly it went directly from Spain to Eastern France at some time between the 14th and 16th century.

This astrolabe is a singularly complicated piece from a historical point of view, replete with details which can help us better understand the whole instrument once we have come to terms with these details, yet it is silent on some of the most important considerations. The scientific, technological, epigraphic, and art-historical aspects are each of prime importance if we are to begin to understand this object.

In the sequel, an attempt has been made to separate description from commentary. The astrolabe cannot be understood without reference to several other early astrolabes, details of which are presented in **Appendixes A-B**.[13] Much of the comparative material used in this study is taken from the catalogue of medieval Islamic and European instruments currently in preparation in Frankfurt.[14] Some 40 Islamic astrolabes are known from al-Andalus from before *ca*. 1350, but these are of surprisingly little help, except for one earlier Andalusī piece that betrays the same distinctive design of the throne:

> #154, preserved in the Adler Planetarium in Chicago, Ill., an Andalusī astrolabe by Muḥammad ibn Yūsuf ibn Ḥātim dated 638 H [= 1240/41]—see **Fig. 12**.[15]

Several Islamic astrolabes from Syria or Egypt have silver inlay as does this piece, yet the silver inlay here is not necessarily influenced by the Eastern Islamic tradition but rather by an Andalusī tradition. A few medieval astrolabes have inscriptions in Hebrew (see **3.20**) or

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[11] See Ziegler, *Black Death*, and also the text to n. 260 below.

[12] See the article "Mudéjar" in EI_2.

[13] See King, "Catalogue of Medieval Astronomical Instruments". Instruments are referred to by their numbers in the International Instrument Checklist (see Price *et al*., *Astrolabe Checklist*), here preceded by the symbol #.

[14] The majority of the instruments cited in this study have been catalogued already. It is hoped to put this material on the Internet in the not-too-distant future. For the time being, most readers must have recourse to Gunther, *Astrolabes*, a monumental work riddled with errors and long out of date, various catalogues, and the list of medieval Islamic instruments presented in **XVIII**.

[15] See Gunther, *Astrolabes*, I, pp. 300-301 (no. 154). Gunther unfortunately misdated the piece to 1747 (how, it is not clear). See further n. 128.

additions in Hebrew, yet we are not dealing here with an astrolabe in the Jewish tradition. Not a single surviving astrolabe can be securely associated with Southern France before 1400, or even before 1500; some half a dozen of the numerous instruments that can safely be associated with Northern France from before *ca*. 1400 are of relevance to our investigation. As already noted, only four other European astrolabes are known from the Iberian Peninsula before 1500, all from Catalonia.[16] We shall have occasion to refer to them frequently. These are:

#3042, from the late 10th century and now preserved at the Institut du Monde Arabe in Paris. This was first described in 1956 by Marcel Destombes, who, to his credit, recognized it for what it was.[17] More recently, the piece has been the object of much controversy, not least because our knowledge of early European astrolabes rests on such weak foundations.[18]

#162, from *ca*. 1300 and now in the Society of Antiquaries in London. This elegant piece was first published in 1893, and was featured by R. T. Gunther in his monumental book on astrolabes published in 1932. It has recently been examined in detail.[19]

#416, also from *ca*. 1300 and now in the National Maritime Museum, Greenwich. A full description is shortly to appear in the new catalogue of the Greenwich astrolabes, but some of its features have been discussed in recent papers.[20]

#3053, made in Barcelona by the Aragonese Petrus Raimundus in 1375 and now in the Museum of Fine Arts, Boston, Mass. This remarkable and extremely elegant piece has not yet been published in detail.[21]

We further note three Andalusī astrolabes that have later additions revealing that they came into the hands of Europeans and/or Jews in the Iberian Peninsular already in the Middle Ages:

#116, made in Toledo in 420 H [= 1029/30] and now in the Deutsche Staatsbibliothek in Berlin, has additions in Hebrew, probably also executed in Toledo.[22]

#3622, made in Cordova in the year 1054 and now in the Jagiellonian Museum in Cracow, has additions in medieval Catalan.[23]

#1148, made in Seville in 1230 and now in the Museum of Islamic Art in Cairo, has additions in medieval Spanish, as well as in Hebrew.[24]

No astrolabes with inscriptions in Hebrew survive from medieval Spain. However, a single astrolabe with inscriptions in Judaeo-Arabic, that is, Arabic written in Hebrew characters, survives:

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[16] Descriptions in Catalan based on a text in English by this author are to appear in the volume *La ciència en la història dels Països Catalans* published by the Institut d'Estudis Catalans in Barcelona, currently in press.

[17] Destombes, "Astrolabe carolingien".

[18] See the various studies in Stevens *et al*., eds., *Oldest Latin Astrolabe*. See also n. 41 below.

[19] See Gunther, *Astrolabes*, II, pp. 306-309 (no. 162); and King & Maier, "London Catalan Astrolabe", which contains as an appendix the text of the 1893 publication.

[20] See *Greenwich Astrolabe Catalogue* (forthcoming), also n. 16 above. The plates are discussed in King & Maier, "London Catalan Astrolabe", pp. 694-695, n. 60, and the Catalan month-names on the back in Maier, "Romanische Monatsnamen", A, pp. 244-247. The V-shaped frame on the rete was popular on medieval English astrolabes; see King, "Oldest European Astrolabe", fig. 14, for an illustration.

[21] The front is illustrated in King, "Oldest European Astrolabe", fig. 16. See also n. 16.

[22] A detailed description is in Woepcke, "Arabisches Astrolabium". See also Gunther, *Astrolabes*, I, pp. 251-252 (no. 116); Mayer, *Islamic Astrolabists*, p. 75 and pl. II; and n. 242 below.

[23] See Maier, "Romanische Monatsnamen", A, pp. 244-247, and, more especially the detailed description in *idem*, "Ein Astrolab aus Córdoba".

[24] See Maier, "Romanische Monatsnamen", A, pp. 247-249.

#3915, made either in al-Andalus or in the Maghrib *ca*. 1300, and now in the N. D. Khalili Collection in London. The rete design is related to that on #162.[25] There are several problems relating to this piece,[26] for it was made by someone who was more competent in engraving Hebrew script than in understanding Arabic and astrolabes.

Some remarks about recent research on astrolabes are in order here.[27] Altogether some 150 Islamic and some 150 European astrolabes survive from before *ca*. 1500. Each is a historical source that can tell us something, some far more than others. Islamic instruments are usually signed,[28] medieval European ones usually not.[29] Islamic instruments can be associated with various regional schools which are relatively easy to define; for early European instruments there is often no obvious clue to the provenance, and sometimes a given rete design may be, say, English or French or Italian. The study of European rete design is still in its infancy. Islamic instruments are usually dated or easily datable, European ones are seldom dated and we have less control over dating them.[30] A select subgroup of instruments has more than a single layer of inscriptions, from which we can sometimes determine the subsequent fate of the instrument.[31]

Numerous other features can be used to better understand an astrolabe and place it in its historical context:

❖ the engraving (the study of which is likewise still in its infancy) and the numeral forms;[32]

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[25] See King & Maier, "London Catalan Astrolabe", p. 681 and fig. 6 on p. 718.

[26] The description in *Christie's Amsterdam 15.12.1988 Catalogue* is repeated in *London Khalili Collection Catalogue*, II, pp. 214-217 (no. 124). The problems of the instrument are overlooked: the plates and their inscriptions are confused (in other words, the latitudes underlying the markings on the plates do no correspond to the latitudes engraved on the plates) and the lengthy inscription makes no sense. See King, "Review", col. 253. A banal account by Michael Rogers in *Speyer 2004-05 Exhibition Catalogue*, p. 242, again ignores all of the problems.

[27] The best introductions to the astrolabe in English are *Greenwich Astrolabe Booklet*, and Hartner, "Astrolabe", A-B. For Spanish readers García Franco, *Astrolabios en España*, remains unsurpassed; it well deserves reprinting with new illustrations. The origin of some of the standard components on medieval astrolabes is discussed in **XIIIa**.

[28] On Muslim instrument-makers see Mayer, *Islamic Astrolabists*.

[29] Only seven European astrolabes from before *ca*. 1500 are signed. These are: #292, an English astrolabe signed by Blakenei (dated 1342); #304, also English, undated (*ca*. 1400), with a problematic inscription yet to be interpreted; #3053, made in Barcelona by Petrus Raimundus of Aragon (dated 1375); #548, a 14th-century Italian astrolabe, has additional 15th-century markings by Henricus de Hollandia; and #4523, made by Antonius de Pacent in "Lanzano" (dated 1420); #4506, an Italian astrolabe bearing the initials "KP" in Urbino, 1462 (obviously not by an Italian); and #640, dedicated in Rome by Regiomontanus to his patron, Cardinal Bessarion (dated 1462). In the case of the last-mentioned it is not clear whether or not Regiomontanus actually made it, or whether it was made in Rome or Vienna (see King & Turner, "Regiomontanus' Astrolabe", pp. 197-198). See further the next note and also nn. 41 and 42 .

[30] Dated European astrolabes from before *ca*. 1450 are only four in number (see the previous note). These are: #291, an English astrolabe dated 1326; #292, Blakenei's astrolabe dated 1342; #3053, Petrus Raimundus' astrolabe dated 1375; #4523, the astrolabe by Antonius de Pacent dated 1420. On some dated astrolabes of the Vienna school between 1450 and 1500 see King & Turner, "Regiomontanus' Astrolabe", pp. 188-190. On some problems of dating medieval Italian astrolabes see **XIIId-1.1** and **2.2**.

[31] For some examples of instruments with more than one layer of inscriptions see *Nuremberg GNM 1992-93 Exhibition Catalogue*, II, pp. 578-581 (on #548, a 14th-century Italian astrolabe with additional 15th-century markings by Henricus de Hollandia, probably in Paris); King, *The Ciphers of the Monks*, pp. 132 and 141-142 (on #202, from 14th-century Picardy with numbers expressed in monastic ciphers, and with a later dedication dated 1522 from the Humanist milieu of Louvain); and Maier, "Ein Astrolab aus Córdoba" (on #3622, from 11th-century Cordova, with Catalan additions probably from the 13th or 14th century—Maier has 15th century, which is too late). See also *idem*, "Romanische Monatsnamen", B, on European additions to some Islamic astrolabes, including #116 (on which see also nn. 22 above and 148 and 242 below).

[32] A useful guide to relevant number notations is Ifrah, *Histoire des chiffres*. More detailed studies of the Arabic, Hebrew and European notations are listed in nn. 49, 52 and 77. See also King, *The Ciphers of the Monks*, pp. 281-

- the design of the throne and the rete;[33]
- the choice of stars and their names[34] and positions;[35]
- the latitudes and/or localities mentioned on the plates;[36]
- the organization of the solar and calendar scales;[37]
- the existence of additional markings such as a universal horary quadrant, to provide a quick approximate solution to the problem of determining time from solar altitude for any latitude (**XIIa**);
- the nature of the shadow scales (**XIIa-B**); *etc*.

This particular astrolabe even provides new information on the medieval alphabet[38] and the early history of the Hindu-Arabic numerals in Europe.[39]

Instruments have been persistently ignored in studies of medieval metalwork, even though, at least in the Islamic world, they provide the largest single corpus of signed and dated historical objects.[40] There has also been an unfortunate tendency in 20th-century scholarship to dismiss as

317. In this study I use the notation for sexagesimal numbers standard in the modern literature on the history of the exact sciences: thus m;n° stands for m°n′.

[33] See King, "Astronomical Instruments between East and West", p. 160, and also *idem*, "Oldest European Astrolabe", for several illustrations of medieval European astrolabes, in the main previously unpublished.

[34] Arabic star-names are clearly defined and on Islamic astrolabes are generally correctly spelled. On the star-names that one might expect on medieval European astrolabes see Kunitzsch, *Arabische Sternnamen*, based mainly on textual sources; on actual astrolabes there are numerous forms of individual star-names that are even more corrupt than those in the texts. In general it is possible to identify the types of star-catalogues may have been used originally for a particular set of star-pointers, although there are many examples of star-names that have been much corrupted by copying from one instrument to another, without recourse to any manuscripts. The hazards of investigating such names are well revealed by the present study. See also King, "Star-Names on Three Medieval Astrolabes", where the star-names on #4560, #202 and #493, respectively from 14th-century Spain, France and Italy, are investigated.

[35] For the first serious attempt to investigate star-positions on astrolabe retes in the light of medieval knowledge about these positions (and with occasional resort to modern knowledge) see Stautz, *Mthematisch-astronomischen Darstellungen auf mittelalterlichen Instrumenten*.

[36] See King, "Geography of Astrolabes", now in **XVI**, dealing with the geographical data on all Islamic astrolabes to *ca*. 1100 as well as the earliest European astrolabes (including #3042, #416, #162 and #202).

The plates on the earliest Eastern Islamic, Western Islamic and European astrolabes were specifically for the seven climates of Antiquity: see further n. 259 below. On the importance of the climates in medieval instrumentation see King, "Astronomical Instruments between East and West", pp. 152 and 168-169; *idem*, *Mecca-Centred World-Maps*, pp. 24, 27-28 and 230-234; *idem*, *Ciphers of the Monks*, pp. 356-357, 360-361 and 411-415; and now **XVI-2-3**.

[37] These scales feature on the vast majority of Western Islamic and European astrolabes, as well as on some from 12th and 13th-century Syria and Egypt. See further n. 206 below. The dangers of dating instruments solely by the data that can be gathered from the correspondence between the solar and calendrical scales are well known: see Michel, *Traité de l'astrolabe*, pp. 135-141; Zinner, *Deutsche und niederländische astronomische Instrumente*, pp. 138-139; Poulle, "Peut-on dater les astrolabes?"; G. Turner, "Carolingian Astrolabe", pp. 426-429, and *idem*, "Dating Astrolabes".

[38] On the medieval alphabet a, b, ... , z, followed by the symbols & and **9**, especially as used in lists and concordances in medieval Europe, see King, *The Ciphers of the Monks*, pp. 43-45.

[39] Another piece, #202, from 14th-century Picardy, bears numbers in a notation completely different from the Roman and Hindu-Arabic notations: see King, *The Ciphers of the Monks*, pp. 131-151 and 406-419, and also n. 99 below.

[40] A useful introduction is Ward, *Islamic Metalwork*, with almost exclusively Eastern Islamic examples. See also *Granada-New York 1992 Exhibition Catalogue*, pp. 207-223 and 270-295 (some two dozen metal objects from al-Andalus) and 376-383 (four brass astronomical instruments).

fakes instruments that do not fit into known categories.[41] It is symptomatic of the state of the field that the earliest surviving European astrolabe, #3042, was deemed highly suspicious by scholars who could not understand it; no amount of scholarship can now undo the damage that has been done to this piece. Metal analysis has not yet been applied to medieval instruments, except in a rather haphazard fashion to two such supposedly suspect pieces.[42] Nevertheless, the study of medieval astronomical instruments in general and astrolabes in particular has taken enormous strides in recent years.[43]

2 Description of the astrolabe

1 Introductory remarks

The astrolabe is in brass with inlaid silver cartouches on the back. It has a diameter of 133 mm—see **3.7**—and is 5 mm thick. It has been assigned the number 4650 in the International Instrument Checklist.[44]

2 The engraving

The engraving is partly in Latin script, partly in Arabic script, and there are scratches in Hebrew. It is clear that the instrument was started by a Jew, partly engraved by a European and then completed by an Arab, and that the Arab took over the engraving from the European. It may be that they collaborated at least in the inlaying of the silver cartouches on the back, for these were part of the original decoration but the inscriptions on them were engraved by the Arab.

The forms of the Latin letters—see **Fig. 10**—are standard, with one exception. A letter '**9**' resembling, but not identical with, a '9' is used for a hard C (to be pronounced K or Q) in some of the inscriptions. Also, there is one ligature OR. See further **2.8** and **3.2**.

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[41] On #3042 (cited already in n. 18 above) see Stevens *et al*., eds., *Oldest Latin Astrolabe*. Some have thought that this was from the 10th century, others that it was from the late Middle Ages, and a few saw it as a modern forgery.

See also King & Turner, "Regiomontanus' Astrolabe", on #640, an instrument dedicated by the leading astronomer of the 15th century to his patron, which was pronounced suspect after it had been auctioned in 1989. See also the next note.

[42] See, for example, Gratuze & Barrandon, "Nouvelles analyses", for the results of such an analysis of #3042. Here we *are* dealing with a 10th-century instrument but this was not proven by metal analysis because no comparison with contemporaneous metalwork—such as reliquaries, caskets, candlesticks and the like—was conducted. In this case, the engraving and also the astronomical and geographical data that the instrument can yield are more useful. See also King & Turner, "Regiomontanus' Astrolabe", pp. 183-186, for the results of a metal analysis of #640. In this case, the authenticity of the instrument dedicated by Regiomontanus to the Cardinal Bessarion was confirmed by finding ten others from the same workshop. This alas does not answer the question: "who actually made it?" (see n. 29 above). One thing that would be useful now is a metal analysis of the whole corpus.

[43] See King, "Astronomical Instruments between East and West", already outdated, and *idem*, *Ciphers of the Monks*, pp. 364-419.

The study of Renaissance instruments has also taken enormous strides. See G. Turner, "Giusti's Workshop"; *idem* & Dekker, "Astrolabe by Mercator", and *eidem*, "Three Astrolabes by Mercator", as well as G. Turner, *Elizabethan Instruments*. For the 16th-century school in Louvain and its Spanish connection see also van Cleempoel, *Louvain Instruments*, and the same author's contributions to *Madrid FCA 1997 Exhibition Catalogue*. On a newly-discovered instrument in the latter tradition, see Moreno *et al*., "Spanish Astrolabe", with some problems of interpretation.

[44] See n. 13 above.

The European engraver used the medieval European forms of the Hindu-Arabic numerals that were used from the 12th century onwards, with one significant exception. Particularly striking is his use of the "upside-down" '2', which belongs to the forms introduced in Spain in the 10th century.[45] Also, he used bar fractions with the numerator on the bottom and the denominator on the top. See **Figs. 7b-c** and further **2.10** and **3.4-5**.

The Arabic script is *naskhī*, but this does not mean that the engraver was from, say, Syria or Egypt rather than from al-Andalus or the Maghrib. In the 14th century *naskhī* script was used for inscriptions in the Naṣrid Kingdom of Granada, which was still in Muslim hands—see **3.6**.

3 The throne

The throne is elegantly worked with pierced arabesque. This is most unusual on a European astrolabe—see **3.8**.

4 The suspensory apparatus

A circular ring is attached to a shackle fitted at the top of the throne. The shackle has rounded low conical bosses on the front and back. There is an inscription in Arabic on both sides of the boss of the shackle, which identifies the owner—see **Figs. 3a-b**.[46] It reads:

صاحبه الفقير مسعود | الواثق بالملك المعبود

which translates:

"Owned by the needy Masʿūd, who trusts in the King
who is to be worshipped (*i.e.*, God)."

The word *ṣāḥibuhu* has been stretched all around the boss on the front. There is an unhappy *sukūn* (zero-vowel) on the initial *ṣ* (= *ṣād*), and the seat of the *b* (= *bāʾ*) coincides with the top of the *l* (= *lām*) of *al-faqīr* so that the dot is not visible. The *k* (= *kāf*) in *al-malik* has been repeated above the word. There is a criss-cross decoration below the *m-s* of Masʿūd. These details are significant—see **3.6**.

5 The mater

The circumferential scale on the mater is divided into 5° intervals subdivided for each 1° and labelled for each 10° from 10° to 360°—see **3.3-4** on the forms.

Around the rim there are divisions for each 15°, corresponding to each hour of the day. These

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[45] The form is "upside-down" only in relation to the form '2' that later became standard. It is in fact that form, which we use today, which is upside-down with respect to the earliest form of the '2' in Europe, that being derived from one of the several Arabic forms by rotation and some stretching. See Kunitzsch, "Hindu-Arabic Numerals".

[46] The second part of this inscription was incorrectly read as a chronogram in A. J. Turner, "Astrolabe exceptionel" / "Exceptional Astrolabe". The sum of the numerical values of the letters in the phrase *al-wāthiq bi-ʾl-malik al-maʿbūd* is indeed 914, and taking this as a Hijra date, one arrives at an equivalent date of 1508/09 A.D. But making a chronogram out of part of an inscription of this kind goes against the rules of the game, on which see Ahmad, "Arabic Chronograms", and Ifrah, *Histoire des chiffres*, I, pp. 600-604. It *would* be acceptable to use a chronogram in a sentence like "Masʿūd *acquired* it (*imtalakahu* or something similar) /or/ *finished the engraving* (*atamma naqshahu* or the like) ... ".

are numbered from 2-12 and again 1-11 in a later (16th-century) European hand—see **3.4** on these forms too.

The inside of the mater bears no engravings whatsoever. However, the imprints of the silver cartouches on the back and the marks of the hammering to make the brass better receive the molten silver are clearly visible—see **Fig. 5**.

The back (see below) is riveted to the rim of the mater with 14 rivets, whose outlines are all still visible on each side. (On some medieval astrolabes the mater and back are of one piece.[47])

6 The rete

The rete is of elegant and distinctive design—see **Fig. 4a**.[48] There are three half-quatrefoils attached to the inside of the ecliptic ring, each supporting a single star-pointer. The horizontal bar is counter-changed at the ecliptic ring and again between the ecliptic ring and the central circular disc.

Between the lower equatorial bar and the circumferential frame, there is a distinctive small circular frame. A thin bar connects the equatorial frame to the central disc along the vertical diameter. Two small bars in the form of half-quatrefoils join the upper part of the ecliptic ring to the outer frame. There are four silver buttons serving as handles, two on the horizontal frame outside the ecliptic (the one on the left is missing), one at the top of the ecliptic ring and another at the centre of the equatorial frame above the small circle. For more on the design see **3.9-10**.

The scale of the ecliptic is divided into unlabelled 6°-intervals within each zodiacal sign. The signs on the ecliptic ring are named as follows, abbreviated for lack of space in the first half of the ecliptic ring:

ARI—TAU—GEMI—CAN—LEO—VIR
LIBRA—SCORPI—**SAGITA**—*CAPRI*—**ACUARI**—*PISCES*

On the two forms in bold, see **3.3** below. The engraving is not identical to that of the star-names (see below). The equivalent Arabic names are correctly but uncomfortably engraved in the barely adequate remaining space. The forms are the same as those on the back (see below).

The back of the rete bears no astronomical markings other than the circle of the winter solstice on the inner side of the circumferential frame and, on the lower right half of the ecliptic frame, part of the circle of the summer solstice.

7 The star-pointers

Altogether there are 21 star-pointers, with the larger ones having three decorative holes in the base and the smaller ones a single hole. See further **3.11-12**. Another pointer at the left-hand end of the lower equatorial frame is a dummy, serving not only the exigencies of symmetry but also to strengthen the rete.

8 The Latin names of the stars

The names of the stars are engraved differently from the names of the zodiacal signs, but not necessarily by a different person. Their forms are a mixture of Europeanised Arabic and Latin, as

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[47] On #3042 and #162 the back is brazed onto the rim.
[48] R. T. Gunther would have labelled it "Hispano-Mauresque"—see his *Astrolabes*, II, p. 306.

was standard on medieval European astrolabes. A curious symbol '**9**' is used for a hard 'C' (see below). Only in the name RIGORCA (no. 8) does the standard form of the 'C' appear, and this is used throughout on the ecliptic ring. Also there is one ligature 'OR' (again no. 8). The colon (in nos. 18 and 21) is used as a separator. A list of the star-names follows, with those of especial historical interest in bold.

1	PANTA **9**AITOS	12	FE**9**A
2	ALGOL	13	ON**9**E
3	DBRAN	14	**9**OR S**9**ORPI
4	RIGEL	15	UEGA
5	ALABOR	16	RADF
6	**9**OMIZA	17	ALTAIR
7	**9**OR LEO	18	**9**AUD:**9**OARI
8	RIGORCA	19	**9**ABI
9	**9**ORUUS	20	OMER**9**I
10	SPI**9**A	21	DNP **9**AITOS:
11	ALRAME		

See **3.13-14** for comments on the selection of stars and on the names applied to them.

9 The Arabic names of the stars

The Arabic names have been added secondarily to the European names for four stars in the same hand as that on the boss of the shackle:

3	*dabrān* (the standard form is *dabarān*)	13	*al-ḥayya*
6	*ghumayṣa* (the standard form is *ghu-maysā'*)	17	*al-ṭāyir* (the standard form is *al-ṭā'ir*)

See **Fig. 8a** for the first of these and **3.15** for comments on these names.

Also, the Arabic names of most of the other stars (all but no. 19) have been lightly scratched near the pointers in an inelegant hand. The hand is careless and inexact, quite different from that of the main Arabic inscriptions, but the names, in so far as they can be seen, are essentially correct.

10 The three original plates

Each of the four plates bears standard astrolabic markings for altitudes, azimuths and seasonal hours—see **Fig. 6a-b**. The altitude circles are engraved for each 6° and the azimuth circles for each 10°, the latter extending only to altitude 78°. Three of the plates are marked in Hindu-Arabic numerals for latitudes:

1a	$32^1/_2$
2a	40
1b	42
3a	43
2b	45
3b	$49^1/_2$

The fractions are both written $\frac{2}{1}$—see **3.5** below.

The plates for latitudes $32^1/_2$° and 43° each bear a second horizon, both for latitude *ca*. 45°. Both of these additional horizons are lightly engraved and give the impression that the maker started the plates for this latitude and then changed his mind.

The plate for latitude $32^1/_2$° bears fish-bone markings on the altitude circle for 18° between the solstitial circles, which are different from those on the fourth plate—see **2.12** and **3.22**.

These three plates are of different thickness. Their weights in grams are:

P1: 44.4, P2: 49.5, and P3: 53.9.

See further **3.18-19** for further details on the latitudes used on these plates.

11 The inscriptions in Hebrew characters

Near the pegs on each side of these three plates the latitudes, this time in degrees and minutes—32 30, 40, 42, 43, 45, 49 30—are scratched in Hebrew alphanumerical notation, using a Sephardic cursive variety of script (sometimes called *rashī*)[49]—see **Figs. 8b-c** and further **3.20**.

12 The fourth plate

The fourth plate is inscribed on one side in Arabic: *ʿarḍ al-Jazāyir* "latitude of Algiers"—see **Fig. 7d**. The hand is the same as that of the inscription on the boss of the shackle and of the four Arabic star-names on the rete. There is a *sukūn* on the first *r* (*rāʾ*), a second on the *l* (= *lām*) and yet another on the final *r* (= *rāʾ*). A latitude of *ca*. 36°, possibly 35;30°, underlies the astrolabic markings.

This plate for Algiers bears unlabelled curves for the times of the midday and afternoon prayers (*ẓuhr* and *ʿaṣr*). The altitude curve at 18° above the horizon is distinguished by fish-bone markings between the solstitial circles for the prayers at nightfall and daybreak (*ʿishāʾ* and *fajr*). On the other side there are astrolabic markings for an unspecified latitude, which can be determined by inspection to be *ca*. 21;30°, possibly 21;40°, serving Mecca.[50] The altitude circle for 18° bears fish-bone markings, as on the side for Algiers.

This plate may have been prepared in its raw form by the European who made the others. It is slightly thicker than the thickest of the three other plates: it weighs 57.5 grams. Whilst at first

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[49] On Hebrew alphanumerical notation see Ifrah, *Histoire des chiffres*, I, pp. 520-529, and also Gandz, "Hebrew Numerals" (does not deal with medieval usage), and Goldstein, "Hebrew Astrolabe". On various examples of Sephardic cursive script see Birnbaum, *Hebrew Scripts*, I, pp. 263-267, and II, nos. 246-251. In A. J. Turner, "Astrolabe exceptionel" / "Exceptional Astrolabe", the markings in Hebrew script are overlooked.

[50] Kennedy & Kennedy, *Islamic Geographical Coordinates*, pp. 225-226; and King, "Geography of Astrolabes", p. 13, now in **XVI-6**.

sight the astronomical markings resemble those of the other three plates, closer inspection reveals that they were not engraved by the same person. In fact, it seems that the astronomical markings, as well as the Arabic inscription mentioning Algiers, are by Masʿūd. See **3.21-22** for more details.

13 The back

The back—see **Fig. 2**—bears two altitude scales in each quadrant above the horizontal diameter. These are divided for each 5°, subdivided for each 1°, and are labelled for each 10° from 10° to 90° on each side. The corresponding scales below the horizon are divided for each 15° but bear no labels: they define the midpoints of the zodiacal signs on the scale that they bound.

14 The double shadow square

Below the horizontal diameter is a double shadow square, with horizontal shadows labelled OMBRA RE**9**TA and vertical ones OMBRA UERSA. The shadows are to base 12, as was standard in medieval astronomy, and the scales are divided for each four units sub-divided for each unit and labelled for each four units: 4—8—12.

15 The solar and calendrical scales

The solar scale on the back is divided for each 5° of each zodiacal sign, subdivided for each 1° and labelled for each 10°. The excentric calendrical scale is divided for each 5 days, sub-divided for each single day and labelled for each 10, thus: 10—20—n, where n is the number of days in the month (*e.g*., 31 for January, 28 for February, *etc*.). The equinox on the solar scale corresponds to March $13^{1}/_{3}$ on the calendrical scale. The other equinox is at September $16^{1}/_{2}$, and the solstices at June $15^{3}/_{4}$ and December $14^{1}/_{3}$. See further **3.23-24**.

16 The silver cartouches

The silver cartouches for the names of the signs of the zodiac and the months on the back were inlaid at the same time as the graduated scales were engraved. Their borders are contiguous with the circles bounding the scales. The extremities of the "rectangular" cartouches are in the form of a half-quatrefoil. See further **3.25-26**.

17 The names of the zodiacal signs

The names of the zodiacal signs on the solar scale are in Arabic, engraved on the first set of inlaid silver cartouches. The names are the standard Arabic ones, namely:

al-ḥamal—al-thawr—al-jawzā[ʾ]—al-saraṭān—al-asad—al-su[n]bula—
al-mīzān—al-ʿaqrab—al-qaws—al-jady—al-dalw—al-ḥūt

The *hamza* at the end of *al-jawzā*ʾ has been omitted, as has the *n* (= *nūn*) in *al-sunbula*. On these names various Arabic letters or alphanumerical letters or vowel-signs are also engraved. In the following list and hereafter, Ø denotes a *sukūn* or zero-vowel sign, and *a*, *i*, *u* the vowels, written in the inscriptions as *ā* (= *alif*), *y* (= *yā*ʾ), and *w* (= *wāw*);[51] * denotes a *shadda*, the sign denoting

[51] As noted in Wright, *Arabic Grammar*, I, p. 8, the standard vowel signs are probably originally derived from these corresponding weak consonants.

a doubled consonant, and ʾ represents the weak guttural *hamza*. The additional symbols are:

al-ḥamal: Ø—Ø—*u*	*al-thawr*: *u*—*a* or Ø (squashed)
al-jawzā: Ø (altered)	*al-saraṭān*: no marks
al-asad: Ø—*z* (= *zāy*)—*d* (= *dāl*)	*al-sunbula*: ʾ—*a*—*i*
al-mīzān: *ḥ* (*ḥāʾ*) or *j* (= *jīm*)—Ø	*al-ʿaqrab*: Ø—Ø
al-qaws: Ø—*a*	*al-jady*: *a*
al-dalw: *a*—*	*al-ḥūt*: ʾ—*a*

These, along with various criss-cross patterns and flourishes, have been used as a kind of decoration. Yet their presence and organization is not entirely fortuitous—see **3.27** and **3.29** below.

18 The month-names

The month-names on the calendrical scale are also engraved in Arabic in the second set of inlaid silver cartouches. They are unvowelled, as is usual:

ynāyr—*fbrābr* [*sic* for *fbrāyr*]—*mārs*—*ʾbryl*—*māyw*—*ywnyh*—
ywlyh—*ʾghsht*—*shtnbr*—*ʾktwbr*—*nwnbr*—*djnbr*

Again there is a surplus of *sukūn*s, namely, on the final *r* (= *rāʾ*) of *fbrʾbr*, on the *w* (= *wāw*) of *mʾyw*, the *w* of *ywlyh*, and the *sh* (= *shīn*) of *ʾghsht*. In addition there are *shadda*s on the *s* (= *sīn*) of *mʾrs*, the *t* (= *tāʾ*) of *shtnbr*, the *k* (= *kāf*) of *ʾktbr*, and the *w* of *nwnbr*. These are of particular interest—see **3.28**.

Next to these names is engraved a number in Arabic alphanumerical notation:[52]

alif—*dāl*—*dāl*—*zāy*—*bāʾ*—*hāʾ*—*zāy*—*tāʾ*—*wāw*—*tāʾ*—*dāl*—*wāw*
1—4—4—7—2—5—7—3—6—**3**—4—6 .

The associated numbers are for finding the *feria* or day of the week (the third value from last should be 1 not 3). Thus if the year starts on a Sunday (=1), February will start on a Wednesday (= 4), *etc*.

19 The alidade

The alidade—see **Fig. 5**—is of the counter-changed variety with a square plate at the centre and clef decoration at each end. The rectangular sights each have a circular hole 2 mm in diameter and a semicircular cut-out in the half of the base which sits free of the radial stems. A small circular ring attached to the head of a screw with washer fits inside a hollow cylindrical shaft attached to a ribbed circular disc. This appears to be original—see **3.31**.

[52] On Arabic alphanumerical notation see Irani, "Arabic Numeral Forms"; Kunitzsch, "Letters in Geometrical Diagrams", table 1 on p. 14; and also Ifrah, *Histoire des chiffres*, I, pp. 582-591.

3 Commentary

1 Five layers of inscriptions

We can distinguish five different layers of inscriptions, of which the main ones, namely, the second and third, appear to be contemporaneous and the first cannot have preceded them by very long (a matter of days at the most). The fifth layer was certainly added a long time thereafter (16th century?).

1 The Hebrew inscriptions scratched on three of the plates, apparently intended only as an *aide-mémoire* to the maker.
2 The "Latin" inscriptions[53] on the rete, back and three plates.
3 The Arabic inscriptions on the boss of the shackle, the rete, the back, and the fourth plate. These were all engraved by the first owner, Masʿūd.
4 The second set of Arabic inscriptions scratched on the rete.
5 The 16th-century Northern / Eastern French numeral forms engraved around the outer rim.

The possibility that the Latin inscriptions were engraved by the same person who scratched the Hebrew characters on the plates cannot be excluded. Thus we would have four different layers (with 1a and 1b by the same person):

1a The Hebrew construction marks on the plates.
1b The "Latin" inscriptions on the rete, back and three plates.
2 Masʿūd's Arabic inscriptions on the boss, the rete, the back and the fourth plate.
3 The second set of Arabic inscriptions on the rete.
4 The Northern / Eastern French numeral forms around the outer rim.

Yet another possibility must be mentioned, namely, that the first and fourth of the five sets of inscriptions were made by the same person, after the Latin and the main Arabic inscriptions had been completed and presumably after the instrument had passed out of the hands of Masʿūd, its first owner. The probability that a Jewish owner would engrave the latitudes in Hebrew alphanumerical notation for his own purposes (rather than for construction purposes) and would have added the second set of Arabic markings should be considered. In favour of this hypothesis, there is the fact that both sets are scratched rather than engraved. A Jew competent in Arabic might have thought that the star-names should all be in Arabic, and the Hebrew alphanumerical notation is basically the same as the Arabic one anyway—only the script is different. There is a substantial corpus of inscriptions and literature in Judaeo-Arabic, that is, Arabic written in Hebrew script from medieval Spain and the Maghrib, as well as from other parts of the Islamic world.[54] In other words, we would have four main layers of inscriptions (with 3a and 3b by the same person):

1 The "Latin" inscriptions on the rete, back and three plates.
2 The Arabic inscriptions on the boss, the rete, the back and the fourth plate. These were engraved by the first owner Masʿūd.

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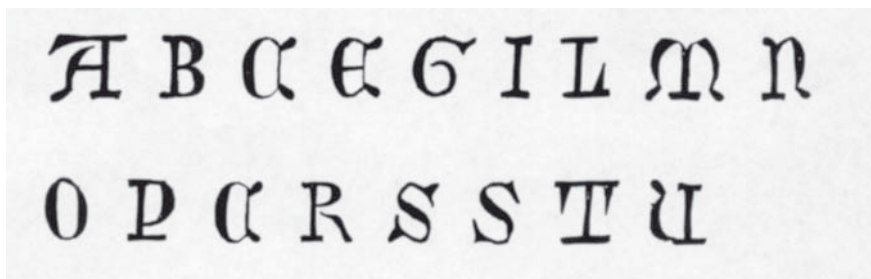
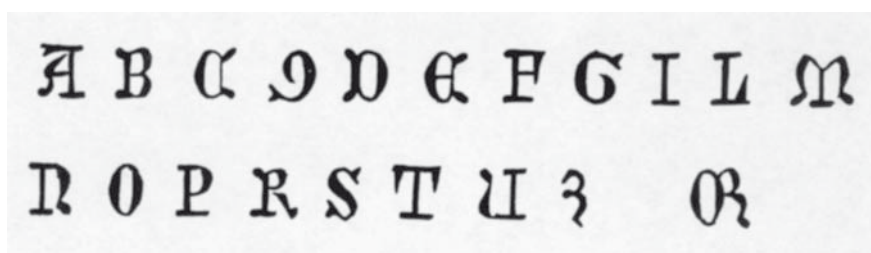
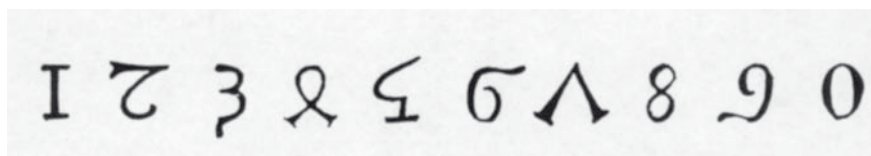
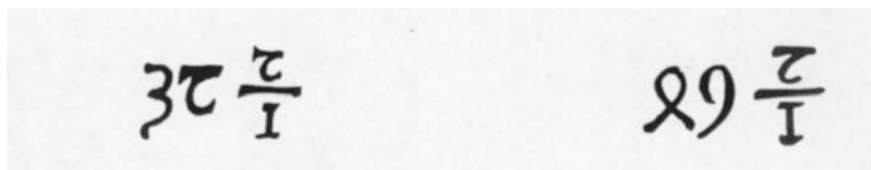
[53] Here and elsewhere the term "Latin" is used advisedly, and in preference to, say, "Gothic". The "Latin" inscriptions include the medieval forms of the Hindu-Arabic numerals on the various scales on the front and back as well as on the plates, the names of the signs on the ecliptic ring, the star-names, and the inscriptions on the shadow-square on the back. Note that the engraving on the ecliptic ring is slightly different and from an orthographical point of view significantly different from that used for the star-names (for example, no '**9**' is used).

[54] See the article "Judaeo-Arabic" by Joshua Blau in EI_2.

The engraving on the ecliptic circle:

The engraving (star-names, shadow-squares on back):

The numerals on the scales on the front and back and on the plates:

The two latitudes featuring fractions:

The numerals on the outer rim:

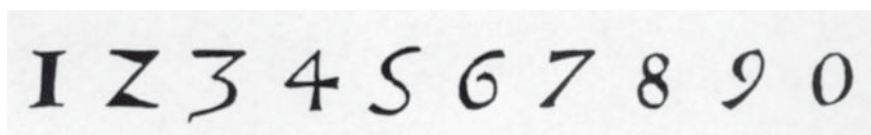



Fig. 10: The forms of the Latin letters and Hindu-Arabic numerals on the astrolabe. [Graphics by Reinhard Glasemann, Frankfurt.]

3a The second set of Arabic inscriptions on the rete.
3b The Hebrew inscriptions scratched on the plates.
4 The Northern or Eastern French numeral forms around the outer rim.

Against this hypothesis is the fact that the second set of Arabic inscriptions was clearly added after Masʿūd engraved his four star-names, for these are not included in the second set.

2 The Latin engraving

The engraving of the "Latin" star-names, the latitudes on the three original plates, and the inscriptions on the back is in a single hand. The engraving of the names of the signs on the ecliptic ring is different, but not necessarily by another person. Both sets of forms of the letters are standard for 13th- and 14th-century Spain.[55] They are shown in **Fig. 10**.[56]

The special '**9**' form for hard 'C', which is used with only one exception in the star-names and also in the word RE**9**TA on the back, but not on the ecliptic ring, is not attested on any other known medieval instrument. A more usual form of 'C' is found in the star-name RIGORCA (no. 8). It seems that '**9**' is used when the sound is a hard 'C' or a 'K' or a 'Q'. The normal 'C' in RIGORCA may mean that it was pronounced RIGORÇA or RIGORSA.

The letter 'Q' was written like '**9**' in certain Spanish manuscripts from the 13th to the 15th centuries,[57] as a result of writing the tail of the 'Q' to the left rather than the right. The hypothesis that the '**9**' here is intended to be a 'Q' is not tenable. For on the astrolabe it is not just 'Q' which is engraved as '**9**' but also, for example, the hard 'C' as in **9**OR and RE**9**TA. And some of the same Spanish alphabets have a 'K' whereas others do not. So we must look beyond the standard alphabets.

The symbol '**9**' is actually a letter of the expanded medieval "Gothic" alphabet.[58] This consisted of the letters 'a' to 'z',[59] and in addition the two letters '&', the "ampersand" that we still use today, and a letter '**9**' which has no name, but which was "so graceful and chaste in early and middle gothic".[60] This '**9**' is attested already in Roman Antiquity: it is mentioned by the grammarian Valerius Probus in the 1st century. Originally conceived as one of the symbols of the Tironian Notes, the Roman speed-writing notation devised by Tiro, *amanuensis* of Cicero (*ca*. 63 B.C.),[61] in the Middle Ages it served firstly as an abbreviation for the prefix *con*- or *cum*- and, secondly, albeit upper-case and in smaller versions which sometimes resemble a comma, the ending -*us*. It is well known to all those familiar with Latin and medieval palaeography and its almost perverse systems of abbreviations,[62] and its presence has already been noted on medieval astrolabes.[63] On

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[55] The resemblance to the engraving on the Catalan astrolabe #162, datable *ca*. 1300, and #3053, made in Barcelona in 1375 by an Aragonese, is striking. On the former see the letters and numbers reproduced in King & Maier, "London Catalan Astrolabe", p. 716, fig. 4, drawn by Reinhard Glasemann, Frankfurt.

[56] These were also drawn by Reinhard Glasemann.

[57] See García Villada, *Paleografía española*, I, pp. 328, 330 and 335, as well as p. 356 *ad* fig. 112 in vol. II, and also López de Toro, *Abreviaturas hispanicas*, tables I-II.

[58] See already n. 38 on this extended alphabet.

[59] With or without certain letters such as 'h', 'j', 'k', 'q', 'v', 'w' and 'y', depending on the language involved.

[60] Quoted from Thomson, *Latin Bookhands*, notes *ad* no. 17.

[61] On the Tironian notes see Kopp, *Lexicon Tironianum*, and Costamagna *et al*., *Not' Tironian'*.

[62] The abbreviation '**9**' is discussed in Chassant, *Dictionnaire des abréviations*, pp. xxxii and xxxiv, Prou, *Manuel de paléographie latine et française*, pp. 67 and 68, and Cappelli, *Lexicon abbreviaturarum*, pp. XXV-XXVI, where

this astrolabe we find the '**9**' used as a letter of the alphabet, which is an extremely rare palaeographic phenomenon, but which must be associated with a particular location and epoch. The question is: can we use this unusual feature to identify the provenance?[64] Until the present time it has *not* been possible.[65] Apparently, the '**9**' was used in 12th-century Aragon for a simple 'S',[66] but the use of '**9**' for a hard 'C' on a 14th-century astrolabe seems to constitute the first (and perhaps only?) evidence of this particular phenomenon, thus being, at least in my opinion, of extreme epigraphic importance,[67] and one that we can only ever hope to understand *within the context of medieval Spanish epigraphy*.

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the two different forms are distinguished; Delisle & Traube, "Signe abréviatif"; Poupardin, "Abréviation"; Schiaparelli, "Note paleografiche", pp. 248-249; Laurent, *De abbreviationibus*, pp. 43-44; and Bischoff, *Palaeography*, pp. 151-168.

For lists of words in Latin and French beginning with this abbreviation see Chassant, *Dictionnaire des abréviations*, pp. 109-112 and 150; and Prou, *Manuel de paléographie latine et française*, pp. 343-349 and 378. Cappelli, *op cit*., pp. 68-85, gives numerous examples but not of '**9**' being used strictly as a letter of the alphabet. Various examples of the standard uses of the '**9**' from medieval Spanish manuscripts are illustrated in Millares Carlo, *Paleografía española*, II, pp. 112-113, pl. 76B, nos. 73-81 (for *con-*) and 85-96 (for *-us*).

On practice alphabets found in medieval sources see Wolpe, "Florilegium Alphabeticum"; the article "Abécédaire" by H. Leclercq in *Dict. arch. chrét*., I, cols. 45-61; and Ullman, "Abecedaria".

[63] An additional 15th-century inscription on a 14th-century Italian astrolabe, #548, reads: *Henric***9** *de Hollandia* **9***posuit me*, where the verb is *composuit*, meaning here "put together in its present form". There is also a plate for *pari***9**, that is, Parisius. See *Nuremberg GNM 1992-93 Exhibition Catalogue*, II, p. 580 (*ad* no. 1.74) and figs. 1.74.3-4.

Likewise, the star-name **9***iuncte* for *coniuncte* is found on an Italian astrolabe #4509 from *ca*. 1300—see *Amsterdam NK 1990 Exhibition Catalogue*, p. 101 (no. 186) and p. 106. The 8th month-name is engraved as *AUG***9***TUS* (*AUG***9***T***9** would be more consistent!) on a 13th(?)-century astrolabe of uncertain provenance, #558—see *Nuremberg GNM 1992-93 Exhibition Catalogue*, II, p. 576 (*ad* no. 1.72).

[64] See the study Sed-Rajna, "Toledo or Burgos?", dealing with illuminations in a corpus of medieval manuscripts.

[65] The following works have been consulted in addition to various catalogues of manuscript collections in Madrid, Toledo and Salamanca:

Madrid MAN Catalogue, on epigraphic inscriptions; Thomson, *Latin Bookhands*, with numerous dated extracts of manuscripts arranged according to provenance; García Villada, *Paleografía española*; Millares Carlo, *Paleografía española*; Gimeno Blay, "Escrituras bajomedievales", alas restricted to collections in Valencia; Cooper, "Language of Late Medieval Aragon", a linguistic review of a corpus of late medieval documents from Upper Aragon; Mateu Ibars, *Braquigrafía de sumas*, on abbreviations in numerous Spanish Latin numerous scholastic texts from the 13th to the 16th century; Mateu Ibars & Mateu Ibars, *Colectanea paleográfica*, dealing with Aragonese manuscripts and richly documented with sample alphabets; Marín Martínez & Ruiz Asencio, *Paleografía y diplomatica*, with numerous regional examples of alphabets; Arnall i Juan & Pons i Guri, *L'Escriptura a les terres gironines*, dealing with examples from Girona; and Usón Sese, *Escritura en Aragón*, dealing with calligraphy in Aragonese texts from the 11th to the 16th century.

From the extracts presented in Thomson, *Latin Bookhands*, it appears that French copyists had more of a predilection for the use of '**9**' for *con-*, *etc*., than their counterparts elsewhere in medieval Europe, but this may be an illusion.

[66] This is stated categorically in Millares Carlo, *Paleografía española*, I, p. 113 ("si lo usó a veces con valor de simple *s*, y así se lo ve en documentos aragoneses del siglo XII"), but the reference is alas a blind one, since the sources referred to in the associated footnote, namely, Delisle & Traube, "Signe abréviatif", and Poupardin, "Abréviation", deal only with the symbol '**9**' in French and Belgian manuscripts.

We also note the use of 'Cc' for 'ç' in a Spanish manuscript dated 1422—see García Villada, *Paleografía española*, p. 352 *ad* facsimile no. 109. There is no distinction made between *c* and *ç* in the organization of an Aragonese glossary from 14th-century Toledo—see Castro, *Glosarios latino-españoles*, pp. 3-5.

[67] I thus beg to differ with two colleagues. Firstly, Paul Kunitzsch of Munich (letter of 6.09.2000) wrote: "I am not sure whether ... the **9** was really intentional for a "hard C", or just simply a graphical variant, a personal [quirk] of the craftsman." Also Martin Hellmann of Heidelberg, who has recently published a doctoral thesis on a medieval

In addition, a ligature OR is used in the same star-name RIGORCA. This particular ligature is common in early (9th- to 12th-century) manuscripts.[68] It is probably not insignificant that a ligature AL is used on the medieval Catalan additions to an 11th-century Islamic astrolabe from Cordova (#3622),[69] as well as on various later medieval astrolabes.

Only once in the recent past has an epigrapher turned his attention to the engraving on a medieval astrolabe, confirming from the distinctive forms used for the lettering what is evident from other aspects of the same instrument.[70] The spadework of epigraphers may eventually lead to a localization of the distinctive Latin engraving of the astrolabe under discussion.

3 Traces of vernacular influence in the Latin inscriptions

Traces of vernacular influence on medieval Latin, let alone vernacular Romance dialectal forms, can be extremely useful indicators of the provenance of instruments. Recently, such evidence has been exploited for the first time.[71]

The form ACUARI for AQUARI(US) may be nothing other than an orthographical variant (C for Q) rather than a dialectal one. In the erroneous star-name CAUD:COARI (no. 18 in the star-list) it seems that we are dealing with a more developed vernacular form (A)COARI. An early-13th-century Andalusī astrolabe from Seville with later Northern Spanish inscriptions (#1148) has AQARI, which our engraver would probably have rendered as A**9**ARI. Both the astrolabe of Petrus Raimundus of Aragon (#3053), made in Barcelona in 1375, and the medieval Catalan additions to an 11th-century astrolabe from Cordova (#3622) have ACARI. The switch *qu* → *c* in Spanish Latin is attested.[72] On the 14th-century Picard astrolabe (#202) we find ACARIUS.[73] SAGITTARIUS was spelled with one 'T' as often in the Middle Ages as it is today.[74]

The form OMBRA for Latin UMBRA reveals Spanish or French vernacular influence. It should be borne in mind that OMBRA is still Latin, albeit with vernacular influence, rather than a true Romance form (such as *sombra* or *ombre*).[75] The same phenomenon of short *u* → *o* is attested in

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commentary to Boethius partly written in Tironian Notes, and has also reviewed my recent findings on a missing connection between Ancient and medieval shorthands (see his "Review of King, *The Ciphers of the Monks*"), points out (private communication on 30.11.2002) that: (1) there was no need in Latin for another symbol for a hard 'C', since 'C', 'K' and 'Q' were available; (2) it would not be abnormal for a scribe to make a 'Q', written '**9**', out of a 'C' to represent a hard 'C'; further (3) a graphic double-form of 'CC' (see previous note) is for him nothing special.

[68] W. Mayer, "Buchstaben-Verbindungen", pp. 36-38. See also article "Paleography" in *DMA*, especially IX, p. 346a.

[69] See Maier, "Ein Astrolab aus Córdoba", pp. 121 and 127. Here the ligature is used in star-names beginning with the Arabic article *al-*, and this feature is all the more remarkable because the star-names are *punched*.

[70] See Mundó, "Analyse paléographique de l'astrolabe 'carolingien'". The basic documentation of letter-forms on medieval instruments is also important: see Glasemann, "Zwei mittelalterliche französische Astrolabien", p. 226. The engraving on Renaissance instruments is under better control, thanks mainly to the labours of Koenraad van Cleempoel and Gerard L'E. Turner.

[71] See Maier, "Romanische Monatsnamen", A-B. In King & Maier, "London Catalan Astrolabe", pp. 686-690, it was the Catalan forms of star-names and month-names that were used to establish the provenance.

[72] Castro, *Glosarios latino-españoles*, p. xliv.

[73] These variants are listed in King, *The Ciphers of the Monks*, p. 411, n. 12. See also Maier, "Ein Astrolab aus Córdoba", p. 126.

[74] See King, *The Ciphers of the Monks*, pp. 410-411.

[75] On the switch *u* → *o* see Castro, *Glosarios latino-españoles*, p. xxxiv. On the fate of UMBRA in Spanish see Corominas, *Diccionario*, V, pp. 298-300, especially p. 298b. See also the Renaissance Italian astrolabe with OMBRA in Gunther, *Astrolabes*, II, p. 331.

the star-names ON**9**E (no. 13), OMER**9**I (no. 20) and (RIG)ORCA (no. 8—see below).

Also in the star-name RIGORCA (no. 8) it seems likely that the ORCA, pronounced ORSA, is from Latin URSA(E). No other explanation comes to mind. Here again the change could be taken to display Spanish or French influence, or even Italian: compare Spanish *osa*, French *ourse*, and Italian *orsa*. In the case of RADF (no. 16) instead of RIDF or REDF it may be that we are witness to a change $i \rightarrow a$ that is also attested in medieval Spanish Latin.[76]

4 Numerical considerations

The numeral forms on the scales of the mater and back, as well as the latitudes on the three original plates, are, with one exception, the standard medieval forms of the Hindu-Arabic numerals.[77] They are shown in **Fig. 10**.

The '2' is always written—as we would say—upside-down. This form of the '2', although not attested on any known astronomical instrument, is found throughout the Middle Ages and as late as the 16th century, although it was generally replaced by the more common upright form, which we use today.[78] One theory proposed to explain why some of these numerals have a different aspect from the Hindu-Arabic numerals that were introduced in Spain is that the numbers on the abacus stones were seen in different aspects depending on where one stood in relation to the device.[79] On the other hand, the inverted form of the '2' is standard in the earliest European forms of the Hindu-Arabic numerals, used from the 9th century to the early 13th, but the forms of the other numerals on this astrolabe are not found in European sources in Spain before the 12th century.[80] Furthermore, no other medieval source, object or manuscript, having this combination of the "old-fashioned" '2' and the "new" "Gothic" forms of the other numerals comes to mind.[81] In the light of our engraver's use of the Tironian abbreviation '**9**' as a letter of the alphabet (see **3.2**), we should at least mention that in 13th-century Toledo the Tironian abbreviation for Latin *et* also looked like an inverted '2'.[82] Could this perhaps be the reason why our engraver preferred this inverted form?

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[76] See Castro, *Glosarios latino-españoles*, p. xxxvi, especially the form *aladada* via perhaps *alhidada* or *alidada* from Arabic *al-ʿiḍāda*, meaning "alidade". This form is not listed in Kunitzsch, "Fachausdrücke der Astrolabliteratur", pp. 527-528 (pp. 73-74 of the separatum).

[77] The most useful single source is Hill, *Arabic Numerals*, based mainly on manuscripts in the British Library. See also Ifrah, *Histoire des chiffres*, II, pp. 341-373, and King, *The Ciphers of the Monks*, pp. 309-317.

[78] Hill, *Arabic Numerals*, pp. 28 and 44. See also Juschkewitsch, *Mathematik im Mittelalter*, p. 355, fig. 98, for some 19 different forms of the '2' from medieval manuscripts (other forms could be added), and Ifrah, *Histoire des chiffres*, I, p. 880 on the development of '2'.

[79] Beaujouan, "Rotation des chiffres".

[80] The two tables of forms in Ifrah, *Histoire des chiffres*, II, pp. 348 and 362, display respectively 23 examples of inverted '2's from between 976 and the beginning of the 13th century, and 22 examples of upright '2's from the period between the 12th century and the early 16th. See, most recently, Burnett, "Abacus at Echternach", pp. 94-95, 102-103 and 106-107, on this inverted '2' in Echternach (Luxembourg) *ca*. 1000.

[81] In a little-known article Piccard, "Les chiffres chez les anciens et les modernes", published in Lausanne in 1860, in the table after p. 194, we do find two sets of digits 1-9 with standard medieval forms of all numerals including '4', '5' and '7', but with inverted '2', of which Piccard claims that these are from Sacrobosco and Roger Bacon. Alas he gives no further information on the sources.

[82] See Thomson, *Latin Bookhands*, *ad* no. 117, a manuscript copied in Toledo in 1253/54, featuring this abbreviation with a long horizontal stroke.

The history of the Hindu-Arabic numerals in Europe has yet to be written.[83] Suffice it to say that first, there existed various forms of the nine symbols and zero-symbol in use in each of the Islamic and Byzantine worlds, as well as in each of Spain and Italy, and second, the upside down variety of the '2' was already old-fashioned by the 14th century. It should be borne in mind that the numerals were engraved on this instrument less than two centuries after they had been introduced in Spain, and that in the vast majority of Spanish manuscripts (not necessarily scientific ones) from the 13th to 15th century Roman numerals rather that Hindu-Arabic numerals are used for dating.

The numeral forms on the outer rim of the mater are shown in **Fig. 10**. These are distinctly 16th-century Northern French or German in form, notably the 'Z'-shaped '2'.[84] This form of the '2' could be Spanish, and is attested there already in the 14th century,[85] but it is the whole set which suggests a later and also a more northerly provenance.[86] Actually, it is the forms of the '4', '5', '7' and '8' that necessitate this late dating. In fact, the ensemble resembles the forms used in the illustrations of the rete and back of an astrolabe (#203) in the treatise *L'usaige de l'astrolabe* by Dominique Jacquinot, printed in Paris in 1545.[87] One may wonder whether these numerals were added in Lorraine, where the astrolabe was to be found, since when we do not know, and until 1998.

5 The bar fractions

The two bar fractions on the plates for latitudes $32^1/_2$° and $49^1/_2$° are the earliest original attestations of bar fractions in Europe on an astronomical instrument.[88] In fact, they are the only undisputed occurences on an instrument before the late 16th century,[89] when we find $^1/_4$ appearing at the end of

[83] Studies such as Lemay, "Arabic Numerals", and Beaujouan, "Rotation des chiffres", like all other modern studies, suffer from the fact that the authors are familiar only with the Latin tradition. Before looking at the forms attested in early medieval Europe it is instructive to note the divergent forms existing in the Islamic world before some of them were transmitted to Europe. For new light on this topic, see Kunitzsch, "Hindu-Arabic Numerals"; and King, *The Ciphers of the Monks*, pp. 309-317.

[84] This form of the '2' is found already in 12th-century French manuscripts (see Ifrah, *Histoire des chiffres*, II, p. 362), on the French astrolabe #428 from *ca*. 1300, and on the astrolabes of the workshop of Jean Fusoris of Paris *ca*. 1400 (see the article in *DSB* and the illustration of #192 in Gunther and in Poulle, *Instruments du Moyen Age*, pp. 20 and 22).

[85] The 'Z' form for '2' is found alongside a rounded '2' on #3053, the astrolabe made in Barcelona in 1375 by an Aragonese: here, however, the 'Z' is, as often as not, written backwards!

[86] It is, of course, possible that these numbers were added in Spain in the 16th century. Thus, for example, the numerals engraved on #165, an astrolabe made in Saragossa in 1558, have a rounded form of the '2' and other standard Renaissance forms. Also the forms of 18 sets of Hindu-Arabic numerals from between the late 15th and the 16th century from Spanish documents presented in Labarta & Barceló, *Números y cifras*, pp. 37 and 45, do not correspond to the numerals added to our astrolabe.

[87] Illustrated in Gunther, *Astrolabes*, II, pp. 350-352 (no. 203).

[88] On the plates of #621, a composite 14th-century Italian (?) astrolabe, one of the latitudes, presumably that corresponding to the location of the maker, is engraved as 43 ∸, that is $43^1/_2$° —see *Munich Astrolabe Catalogue*, no. 2, with illustration. On this form, see also Cajori, *History of Mathematical Notations*, I, p. 311, after Cappelli, *Lexicon abbreviaturarum*, pp. LV and 408, mentioning the 13th century.

[89] On the back of #101, an astrolabe made in Iraq in the 10th century, the markings are all by a European. The solar and calendar scales are improperly constructed, and the very medieval-looking letters of the alphabet are mixed with 16th-century numeral forms on the scales. At the end of February we find $28^1/_4$. All of this engraving seems to be by a 19th-century faker. See further **XIIIc-6** and **XIIId-2.7**.

December (as $31^1/_4$) on calendar-scales of astrolabes from Louvain (workshop of the Arsenius brothers, *etc*.).[90] In some 16th-century additions to an 11th-century Andalusī astrolabe #117, additions doubtless made in Spain, the fraction in the latitude $41\frac{1}{2}°$ on one of the plates is written without the bar altogether.[91] Now on the astrolabe under discussion, the fractions are written—as we would say—upside down, thus: $\frac{2}{1}$—see **Figs. 7b-c**.

The first attestation of bar fractions more or less in the form we know them today[92] is in a treatise on arithmetic by Abū Zakariyāʾ al-Ḥaṣṣār, a 12th- or 13th-century scholar from the Muslim West. Little is known about the life of al-Ḥaṣṣār.[93] (Of course, other forms for fractions were used in earlier Islamic writings on arithmetic; indeed, "our" forms without the bar may have appeared in India at the same time as the Indian numerals.[94]) al-Ḥaṣṣār's treatise was translated into Hebrew by Mōshē ben Ṭibbōn (1240-1275) in Montpellier in the year 1271.[95] This was one way in which fractions were introduced in Europe, but it was not the only way. For they appear already in the *Liber abbaci* (1228) on computation by Leonard of Pisa known as Fibonacci (b. *ca*. 1170, d. after 1240), who was well acquainted with Muslim sources, having worked in Bougie, now in Algeria, then a Pisan trading colony, and having studied there with Muslim scholars.[96] Several later Muslim writers use bar fractions.[97] Later European scholars using bar fractions are Jean de Linières (d. *ca*. 1350), Jean de Murs (14th century) and Nicole Oresme (1320-1382).[98]

We can be certain that the engraver was working in a milieu, probably very restricted geographically and temporally, where everyone wrote them with the denominator on the top and the numerator on the bottom.[99] No other attestations of fractions of this kind are known either from medieval Islamic or European sources.[100] Neither does there appear to be any Jewish/Hebrew

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[90] No backs of standard Arsenius-type astrolabes are illustrated in Gunther, *Astrolabes*, and no fractions appear on those few shown in *Madrid FCA 1997 Exhibition Catalogue*. Four such astrolabes with $^1/_4$ written "properly" are: #411, #439, #486 and #3016 (information kindly provided by Koenraad van Clempoel; these instruments are not listed in Appendix A).

[91] See the detailed description in García Franco, *Astrolabios en España*, pp. 229-235 (no. 12), especially p. 233. The same feature occurs on a newly-rediscovered 16th-century Spanish universal astrolabe #4561—see Moreno *et al*., "Spanish Astrolabe". Indeed, the markings on these two astrolabes may be by the same individual.

[92] On fractions in earlier numerical traditions see the various useful chapters in Benoit *et al*., eds., *Histoire des fractions*. On the "discovery" of decimal fractions by al-Uqlīdisī in 10th-century Damascus, see Berggren, *Episodes*, pp. 36-39, and Djebbar, "Fractions au Maghreb", pp. 225-230. See also Cajori, *Mathematical Notations*, I, pp. 309-314 (overview).

[93] Aballagh & Djebbar, "Découverte", especially pp. 149-150.

[94] Benoit *et al*., eds., *Histoire des fractions*, p. 214.

[95] His treatise is translated in Suter, "Rechenbuch von al-Ḥaṣṣār". On the author see also Sarton, *IHS*, II:1, p. 400, and on his translator *ibid*., II:2, p. 847-850.

[96] Article "Fibonacci" in *DSB*, especially pp. 604-606. The new English translation in Sigler, *Fibonacci's Liber Abaci*, is based on the 1857-62 edition of Boncompagni rather than on any of the numerous manuscripts.

[97] See Djebbar, "Fractions au Maghreb", and Aballagh, "Fractions chez Ibn al-Bannāʾ".

[98] Cajori, *Mathematical Notations*, I, pp. 91-93 (Oresme); and Tropfke, *Geschichte der Elementarmathematik*, pp. 108-114 (general).

[99] Compare the use of monastic numeral ciphers on the 14th-century Picard astrolabe #202 (see n. 39). The reason they were used for all numbers on the astrolabe was that the people for whom the astrolabe was intended, used or at least understood these ciphers. See King, *The Ciphers of the Monks*, p. 141.

[100] See Allard, "Fractions dans les premières arithmétiques latines", and Benoit, "Arithmétiques commerciales françaises".

influence in the form $\frac{2}{1}$.[101] We do find such fractions in China in the 17th century, prompted, however, by linguistic considerations: y *fen zhi* x, "x of y parts", for $\frac{x}{y}$.[102] Such considerations may be at work in the form $\frac{2}{1}$ on the astrolabe: the equivalent in English would be "(of) two parts one". Linguistic considerations apart, the notation is arbitrary: we write $\frac{3}{5}$ because we say "three fifths"; in a language in which people might say the equivalent of "fifths three", they might prefer to write $\frac{2}{1}$. Bar fractions caused some difficulty to the earliest printers in Europe, as we can see from the geographical tables in the Ulm, 1462 edition of Ptolemy's *Geography*, where the denominator of unit fractions is printed in the same font as the other numbers and a minuscule $\frac{1}{}$ printed above with varying amounts of success.[103] And on one of the 16th-century Louvain instruments mentioned above, namely #555 (unsigned and undated), the $\frac{1}{4}$ is actually engraved as $\frac{4}{1}$—see **Fig. 11**.[104] The use of an inverted fraction in the 16th century defies explanation![105] We also note that regular bar fractions in which the numerator is greater than the denominator were known in the Middle Ages and are still in very occasional use today.[106]

In the future, it may be possible to locate other relevant historical sources in which fractions are inverted. In Spain even in the 15th century, entries in some astronomical tables were written sexagesimally in Roman numerals,[107] although the *Alfonsine Tables* corpus used Hindu-Arabic numerals.[108] Arithmetic there in the late Middle Ages seems to have been dominated by the Latin tradition of al-Khwārizmī,[109] in which the Hindu-Arabic forms are introduced but Roman numerals are used throughout the text. We shall thus have to look elsewhere for such attestations: financial

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[101] See Lévy, "Fractions en hébreu".

[102] K. Chemla and C. Jami have drawn attention to a "similar" phenomenon in 17th-century China: see Chemla, "Fractions en Chine", especially pp. 190-191, and Jami, "Chinese and Western Arithmetics in the 17th Century", pp. 360-361.

[103] Illustrated in Peignot & Adamoff, *Chiffres*, p. 67. Even here a medieval form of the '5' is used. On the problems of printing fractions of the form $\frac{m}{n}$ and the predilection of printers for fractions in the form $^{m}/_{n}$ (using the "*solidus*", that is, the slash '/') see Cajori, *Mathematical Notations*, I, pp. 312-314.

[104] See *Nuremberg GNM 1992-93 Exhibition Catalogue*, p. 599 and fig. 1.82.7, with the remark "gerade solche Details könnten bei der Analyse anderer Arsenius-Astrolabien oder verwandter Instrumente weiterhelfen", that is, "precisely such details (as this inverted fraction) could be useful for further analysis of Arsenius astrolabes and related instruments"!

[105] There is no trace of this phenomenon in the extracts from early printed works on arithmetic surveyed in Smith, *Rara arithmetica*. For bar fractions using Roman numerals in an early-16th-century German arithmetic see *ibid*., pp. 105 and 106.

[106] Note the forms (n+p)/n or (2n+p)/n relating to music theory in a Mozarab manuscript of the *Arithmetic* of Boethius (d. *ca*. 525—see *DSB*), datable to the 10th or early 11th century—see Millás Vallicrosa, *Assaig*, pp. 91-92, also cited in Vera, *MME*, p. 80.

In passing we note the following remark in Singmaster, "Mathematical Gazetteer of Britain", p. 16:

"Near Harrowgate station is a hairdresser's named 'Twenty Two over Seven'. The owner is a Polish refugee with a long name like Pychovski which was simplified to Pye (?). As a result he tried to name his business 'Π', but the local council, telephone company, etc., couldn't deal with a name using a Greek letter. He then tried to name it '22/7' but had the same problem, so he had to spell out the numbers. His shop window has 'Π', '22/7' and 'twenty two over seven' all painted on it."

[107] See Chabàs & Roca, *Lunari de Bernat de Granollachs*, and Cátedra & Samsó, *Astrología de Enrique de Villena*.

[108] Illustrated in *Cádiz-Algeciras 1995 Exhibition Catalogue*, p. 266.

[109] See, most recently, Folkerts & Kunitzsch, "al-Khwārizmī".
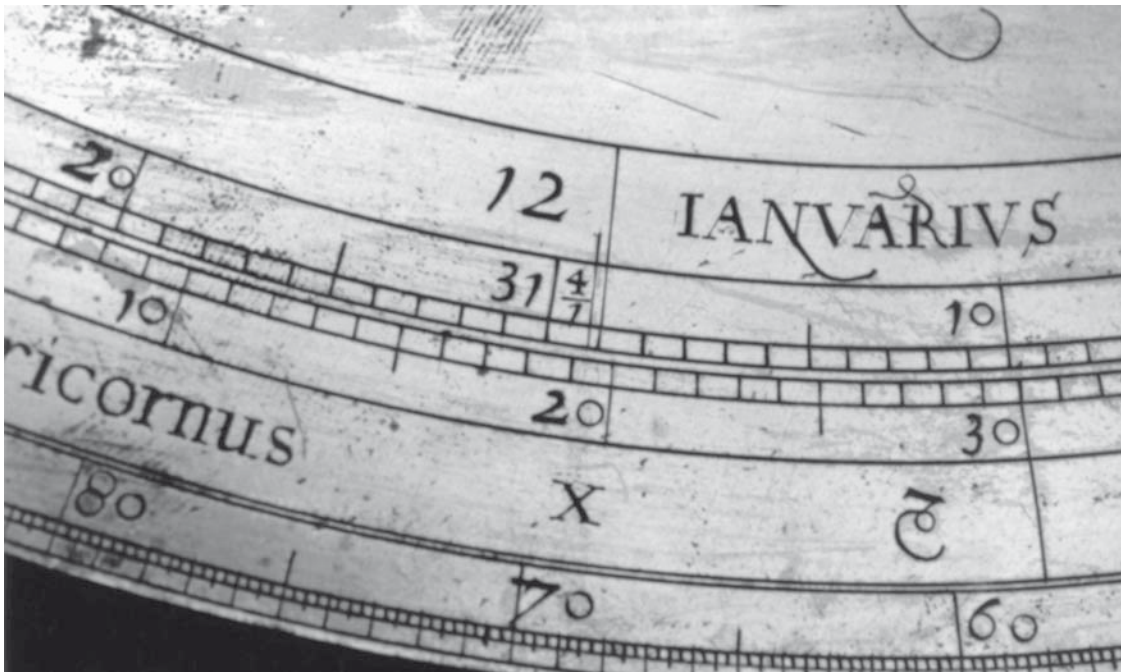
Fig. 11: The fraction $^1/_4$ engraved as $\frac{4}{1}$ on the calendar scale of an unsigned astrolabe from 16th-century Louvain (#555). [Photo by the author, courtesy of the Germanisches Nationalmuseum, Nuremberg.]

accounts,[110] weights and measures,[111] tide-tables,[112] and the like. Preliminary investigations in these areas have borne no fruit. But it is clear that we are dealing here with a development independent of the Khwārizmī—Ḥaṣṣār / Ben Ṭibbōn—Fibonacci traditions.[113] There were other short-lived independent traditions: one 14th-century manuscript of unidentified provenance uses a convention in which three-fifths is written $3\,\frac{}{5}$, *etc*.[114] To put it another way, there is no reason why a European in Central or Northern Spain in the 14th century should have written the latitude of Jerusalem as $32\frac{1}{2}$ rather than $32\frac{2}{1}$. Fibonacci would have written it as $\frac{1}{2}$ 32 anyway.[115]

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[110] An equivalent to Benoit, "Arithmétiques commerciales françaises", for the Hindu-Arabic numerals in Spain would be useful. But see n. 113 below.

[111] See, for example, Kisch, *Scales and Weights*, a useful work but deficient on Spanish materials. I have not yet consulted Mateu y Llopis, *Ponderales monetarios*.

[112] See Howse, "Early Tidal Diagrams", where unusual numeral forms do occur.

[113] Other independent, mainly regional, developments in medieval Spain are noted in Labarta & Barceló, *Números y cifras*, where there is, alas, no mention of inverted fractions.

[114] Eneström, "Bezeichnung von Brüchen", citing MS Vatican Ottob. 399 of a medieval Latin treatise, undated but from before 1350. Eneström concludes his note with the remark:

> "Vielleicht gab es im christlichen Mittelalter noch andere Weisen, die gewöhnlichen Brüche zu bezeichnen, und für die Geschichte der mathematischen Sprache wäre jedenfalls eine nähere Untersuchung der Frage von Interesse."

This unusual variety of fraction is also mentioned in Cajori, *Mathematical Notations*, I, p. 311.

> "Leonardo read from right to left, as did the Arabs ... . In the case of a mixed number, like 3 $^1/_5$, Leonardo and the Arabs placed the integer to the right of the fraction."

6 The Arabic engraving

All of the principal Arabic inscriptions are in *naskhī* script,[116] which at first might be taken as clear evidence that their engraver was neither an Andalusī nor a Maghribi. Rather, they are what one would expect of a Syrian or Egyptian engraver. The use of regular *naskhī* script in the engraving of early Islamic astrolabes is rare; usually Kufic script or ornamental *naskhī* script was preferred. But already in the 13th century, at least in Egypt, we find regular *naskhī* script used on an astronomical instrument—see #107, an astrolabic plate made by Ḥasan ibn ʿAlī in Cairo in 681 H [= 1282/83].[117]

Yet *naskhī* script was used in some Andalusī inscriptions in the 13th-15th centuries, in particular in a series of 14th-century poetic inscriptions in the Alhambra in Granada.[118] Likewise, *naskhī* script is used on an ivory box from 14th-century Spain, which was previously thought to have been Egyptian.[119] Nevertheless, no other astronomical instruments engraved in *naskhī* script are known from al-Andalus.

The Arabic on the boss of the shackle, the rete and the back are all by the same person. One may note the distinctive form of the solitary (*i.e.* initial or final unconnected) *d* (= *dāl*), with a curved inward hook at the lower extremity.[120] This form is found, for example, on the boss, in the name *Masʿūd*; on the rete, in the star-name *dab(a)rān*; and on the back, in the name *dvjvnbvr* for December (where *v* is any vowel). It is a classical calligraphic form,[121] and is also found on the Alhambra inscriptions and the ivory box mentioned above. Also a small number of the letters in the Arabic inscriptions are repeated in miniature above the actual letter, like the *d* in the name *al-asad* on the ecliptic scale on the back and the *k* (= *kāf*) in *al-malik* on the boss of the shackle. This practice is unusual but it is not "wrong".[122] The criss-cross decoration so prominent in the inscriptions on the back is also found in the inscription on the boss of the shackle, under the letters *m-s-* in the name Masʿūd.

The forms of the month-names are entirely within the Western Islamic tradition. There is only

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[116] On Arabic scripts see, for example, the article "Khaṭṭ" [= script] in EI_2, Safadi, *Islamic Calligraphy*, and Schimmel, *Calligraphy and Islamic Culture*.

[117] It has been suggested that the maker was the Cairo astronomer of Maghribi origin, Abū ʿAlī al-Ḥasan ibn ʿAlī al-Marrākushī—see the article "al-Marrākushī" in EI_2.

[118] On the emergence of *naskhī* in Andalusī inscriptions in the 14th century see Fernández-Puertas, "Calligraphy in Al-Andalus", pp. 663-665, and also pl. III.9, as well as the title-page of Gabrieli, ed., *L'Islam en Europe*, for one of the inscriptions in the Alhambra, amply provided with *sukūn*s and vowels. See also Welch, *Muslim Calligraphy*, p. 72, no. 17, for a 14th- or 15th-century terracotta font from Muslim Spain, also with decorative *naskhī* script in oblong cartouches.

[119] Featured in *Venice 1993-94 Exhibition Catalogue*, pp. 115-116 (no. 32). The inscription exhibits some curious orthographical features and is decorated with what look like *sukūn*s all over the place.

[120] Arabic letters can have up to four different forms, depending on whether they stand alone or at the beginning, middle or end of a word.

[121] Schimmel, *Calligraphy and Islamic Culture*, p. 18.

[122] See Lings, *Quranic Calligraphy and Illumination*, pl. 28, on a *Qurʾān* from late 13th-century Baghdad in which most of the letters ʿ (*ʿayn*), *ṣ* (*ṣād*) and *ṭ* (*ṭāʾ*) have a minuscule letter repeated below and the final *k* (*kāf*) above. Other examples are to be found *ibid*., pls. 41, 51 and 57. The purpose here seems to be to distinguish the letters from the three corresponding letters with a dot: *gh* (*ghayn*), *ḥ* (*ḥād*) and *ẓ* (*ẓāʾ*). The repetition of the *k* is particularly common in Arabic calligraphy, to distinguish the letter from the final *l* (*lām*). This phenomenon is not to be confused with the use of small letters above words in the *Qurʾān* as a guide to recitation, marking, for example, pauses.

one error, which is probably not significant: one dot has been omitted on the *y* (= *yāʾ*) in the word *fabrāyir*, making it read *fabrābir*.

The secondary Arabic inscriptions, the star-names scratched on the rete, are in a distinctive hand, quite different from that of Masʿūd. In particular, we note the downward stroke for the final *d* (= *dāl*) on *asad* (for Leo), rather like a final *n* (= *nūn*) in written cursive Hebrew, and the forward (towards the right) sloping vertical stroke of *ṭ* (= *ṭāʾ*). This is a typical Andalusī or Maghribi phenomenon.

An only partly successful attempt has been made to scrape off the Latin name of the star **9**OR S**9**ORPI on the upper right of the circumferential frame of the rete. Presumably, the person who added the second layer of Arabic star-names did this and then gave up trying to remove the remaining inscriptions. On various early Islamic astrolabes, we can see similar attempts by Europeans to remove the Arabic inscriptions and replace them with Latin ones—for example, #110[123] and #1077.[124] On one medieval European astrolabe (#460), from the Fusoris workshop in Paris *ca*. 1425, some of the inscriptions have been removed and replaced by Arabic ones in a Syrian or Egyptian hand, probably as late as the 19th century. Alas, there are no changes to the calendrical scale on the back, which could have identified the location of these modifications more closely.

7 The size of the astrolabe

The diameter of this astrolabe is 133 mm, which may be characterised as average when compared with the diameters of the four medieval astrolabes from Catalonia and the one astrolabe with Judaeo-Arabic inscriptions:

#3042, late 10th century	154 mm
#162, *ca*. 1300	100
#416, *ca*. 1300	147
#3053, Barcelona, 1375	109
#3915, Judaeo-Arabic, *ca*. 1300	185

No other early medieval European astrolabes have diameter 133 ± 2 mm, except #291, an English piece dated 1326, which has 134 mm.[125]

8 The throne

The arabesque decoration[126] of the throne is most unusual for Western Islamic astrolabes and early European astrolabes. It might be thought that this throne shows distinct Syrian influence.[127] However, an Andalusī astrolabe made in 638 H [= 1240/41] (#154) has a throne that is almost

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[123] See Gunther, *Astrolabes*, I, p. 244 (no. 110), and King, "Oldest European Astrolabe", fig. 3.
[124] Maier, "Romanische Monatsnamen", B, pp. 261-262.
[125] See Price *et al*., *Astrolabe Checklist*, pp. 44 and 78.
[126] See the article "Arabesque" in EI_2.
[127] We may compare the thrones on #140, the universal astrolabe of Ibn al-Sarrāj, made in Aleppo in 729 H [= 1328/29] (**XIVb-5**), and #106, a universal plate made in Cairo (?, the calendar scale has the Coptic months) in 699 H [= 1299/1300] by Ibrāhīm al-Dimashqī. See also n. 209 below. This kind of arabesque decoration on thrones is exaggerated on #109, made by the Yemeni Sultan al-Ashraf in 1291: see **XIVa**.

identical, if less elegantly worked—see **Fig. 12**.[128] A simpler, but not dissimilar design, is also found on #4182, made in Fez in 719 H [= 1319/20] by a maker whose family, if not he himself, hailed from Cordova—see **Fig. 13a**. Thus it is not necessary to suppose any direct Syrian influence. The individual elements of the throne are found on other Andalusī pierced metalwork, as, for example, a spectacular lamp made in the royal workshops of the Naṣrid court at Granada for the mosque of the Alhambra in 705 H [= 1305/06], now in the Museo Arqueológico Nacional in Madrid.[129]

The shackle is more European than Islamic, the closest being that on #416, from Catalonia *ca*. 1300, on which the boss, however, is radially ribbed outside the circular central part.[130]

9 The basic form of the rete

The design is mainly, if not fully, Islamic in conception. In other words, the quatrefoil decoration within the ecliptic, the form of the star-pointers, the small circle at the bottom of the rete, and the counter-changing of the horizontal diameter are Islamic.

The three half-quatrefoils inside the ecliptic ring are not attested amongst the numerous varieties of quatrefoil decoration on European astrolabes, which might seem to imply some European input here. But the quatrefoil was a feature of the design of certain Byzantine and early Islamic astrolabe retes, and it is found on some early European retes. Certainly no Islamic retes are known with half-quatrefoils. Yet here the half-quatrefoil frames perform their original function as supports for star-pointers, whereas on later European retes the quatrefoils are more often merely decorative. This may be taken as additional evidence that even the quatrefoil design used here is entirely Islamic in conception.[131] For example, that the "Gothic" quatrefoil design on #162, a Catalan astrolabe from *ca*. 1300, is copied entirely from an Islamic rete, the design being partly Eastern Islamic (and therefore Byzantine in origin), namely, the quatrefoil, and the rectangular frame which it decorates being Western Islamic.[132] As confirmation of the latter, we may invoke #3915, the Maghribi or Andalusī astrolabe from *ca*. 1300 with inscriptions in Judaeo-Arabic: this has a slightly less elegant form of the rectangular frame and a degenerate quatrefoil.[133] In other words, the retes on both #162 and #3915 were copied from a rete on a Western Islamic astrolabe of which no examples survive. As proof of how little we know about the design of Western Islamic astrolabes between *ca*. 1100 and *ca*. 1300 we need only cite #154, made somewhere in al-Andalus in 638 H [= 1240/41], having two larger decorative quatrefoils on the rete—see **Fig. 12**.[134]

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[128] As stated in n. 15 above, this piece is misdated to 1747 in Gunther, *Astrolabes*, I, p. 300. The Hijra date is written *kh-l-ḥ*, that is, 638.

[129] See *Granada-New York 1992 Exhibition Catalogue*, pp. 276-277 (no. 57).

[130] The shackle on #134, decorated with a lion's head, is not necessarily original to this Andalusī astrolabe datable *ca*. 1220. Likewise, the shackle on #154, made in al-Andalus in 1240/41, on which the throne has the same form as that on the astrolabe under discussion, is different in design. On the other hand, the shackle on #162, from Catalonia *ca*. 1300, is rather similar.

[131] On quatrefoil decoration on astrolabes in general see King, *The Ciphers of the Monks*, pp. 380-390, and now **XVII**.

[132] King & Maier, "London Catalan Astrolabe", pp. 679-683; and King, *op. cit*., pp. 382 and 387.

[133] King & Maier, *op. cit*., pp. 681; and King, *op. cit*., p. 382.

[134] *Ibid*., pp. 382 and 386.

Fig. 12: The distinctive rete and distinctive throne on an Andalusī astrolabe dated 638 H [= 1240/41] (#154). Note the two quatrefoils on the rete and the arabesque decoration that is so similar to that on the 14th-century Spanish astrolabe. [Photo courtesy of the late Roderick Webster, Adler Planetarium, Chicago, Ill.]

Figs. 13a-b: The front and back of an astrolabe made in Fez in 719 H [= 1319/20] by Muḥammad ibn Qāsim al-Qurṭubī (#4182). Neither the distinctive rete nor the throne bears any relationship to any other known Maghribi astrolabe. Since the maker or his family came from Cordova, we are dealing with a piece that reflects Andalusī influence. In fact, the basic design of the rete, with the upper equatorial frame and two circular frames, is the same as that on the astrolabe illustrated in the *Libros del Saber* (see *Santa Cruz 1985 Exhibition Catalogue*, p. 25, or *Madrid MAN 1992 Exhibition Catalogue*, p. 60), and the relationship needs to be investigated further. On the back there is a quatrefoil cartouche, not found on any other Islamic instrument and again probably indicative of Andalusī influence: see **XVII-2**. [Present location unknown, photos from the archives of the late Alain Brieux, courtesy of Dominique Brieux, Paris.]

The half-quatrefoils on the short bars connecting the ecliptic ring to the outer frame on the astrolabe under discussion also merit further comment. The idea is Islamic, because we find a *miḥrāb*-shaped design in the same position on the 11th-century Toledo astrolabe #117, and a similar "half-quatrefoil"-type design, albeit with a not quite rounded middle arc, on #4182, an astrolabe made in Fez in 719 H [= 1319/20] by an Arab Muslim whose family origins were in Cordova; this shows not a trace of European influence—see **Fig. 13b**. Similar bars are found on #162 from Catalonia *ca*. 1300, and a like decoration is found on the supports of the lower equatorial ring on #300, possibly of Northern French origin and also datable to *ca*. 1300—see **Fig. 14**.

The counter-changes on the horizontal bar are shown here in an exaggerated schematic form:
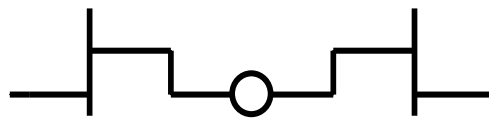
Fig. 14: The front of an astrolabe (#300) with half-quatrefoil insets on the frames supporting the lower equatorial bar, and with star-pointers that bear some resemblance to those on the Spanish astrolabe under discussion (see **3.11**). See **Fig. X-10.2a** for the back of this instrument. [Courtesy of the Museum of the History of Science, Oxford.]

This arrangement is found on seven 11th-century Andalusī astrolabes (including #1099),[135] and some later, but still early European instruments (#428 from France; #191, a composite piece of uncertain origin(s), but with rete possibly reworked from an Andalusī one; and #558 of uncertain provenance).

A small circle similar to the one at the bottom of this rete is found already on 11th-century Andalusī astrolabes (such as #116 and #123) and on some of the astrolabes of al-Khamāʾirī of Seville *ca*. 1220 (such as #130, #139 and #153), as well as on #4182, made in Fez *ca*. 1320—see **Fig. 13a**. On the Andalusī piece #154, dated 638 H [= 1240/41], this circle is replaced by a quatrefoil, which may have been the original design. Only on one other European astrolabe, #420, a very early piece of uncertain provenance (*ca*. 1200, if not earlier), does this small circle reappear. However, it also features on the astrolabe illustrated in the 13th-century *Libros del saber de astronomía* of Alfonso X.[136]

The four "cardinally-aligned" handles in the form of silver knobs are situated near the extremities of the horizontal bar (the one on the left is missing), at the top of the rete, and above the small circular frame. The same arrangement is found on some 11th-century Andalusī astrolabes (such as #116, #123 and #2527) and various astrolabes of al-Khamāʾirī of Seville *ca*. 1220 (such as #130 and #139). However, it is not found on any of the other early European astrolabes, possibly because many of them have radial rules attached to the front.

10 Observations on the quatrefoil

The quatrefoil, one of the most distinctive motifs of medieval European art and decorative architecture, is generally regarded as little more than that. It is true that quatrefoils are found, for example, on some early Anglo-Saxon artefacts; however, the origin of the quatrefoil as one of the principal motifs in late medieval Christian art is to be sought in Byzantine art, transmitted from Syria to al-Andalus. It is an important motif of Andalusī decorative art, albeit usually not independent of other designs (in other words, connected to other designs) and often developed beyond the simplest form.[137] A design including rounded quatrefoils, with rounded half-quatrefoils forming part of the surrounding frame, is found on a sockel of the Peinador Bajo in the Alhambra.[138] This is a rare use of half-quatrefoils, and corresponds precisely to their use on the rete of the astrolabe under discussion.

Now, as already noted, the quatrefoil also featured as a motif on Byzantine astrolabes, and this motif was incorporated on some of the earliest astrolabes from the Islamic East.[139] Somehow, the

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135 For more details see King, "Oldest European Astrolabe", pp. 367-369. The two earlier Andalusī astrolabes, #110 and #4024, have simpler (single) counter-changes, which is already a development beyond the straight bars on the earliest Eastern Islamic astrolabes.

136 Reproduced in *Santa Cruz 1985 Exhibition Catalogue*, p. 25; and *Cádiz-Algeciras 1995 Exhibition Catalogue*, p. 171.

137 For decorative art in Andalusī architecture the best study is Pavón Maldonado, *El arte hispanomusulman*. On the quatrefoil and variations thereon see *ibid*., pp. 69-75, and figs. 98, 102, 104 (no. 23), and pls XLIIb and CLXII (Alcázar, Seville), CLXXIV (Casa de Pilatos, Seville), and CLXXXIV (Madīnat al-Zahrāʾ).

138 *Ibid*., fig. 98.

139 See King, "Kuwait Astrolabes", pp. 80 and 82-89, especially p. 85, on the quatrefoil on the rete of the magnificent astrolabe of the astronomer-mathematician al-Khujandī (#111), made in Baghdad in 984/85; *idem* & Maier, "London

same motif came to appear on some of the earliest astrolabes in Islamic Spain. The earliest known example is #154 from *ca*. 1240, with two fully developed quatrefoils, but this is alas the only example! It simply shows how little we know about this development. We have already noted the half-quatrefoils on the bars between the ecliptic and circumferential frame on #4182, made in Fez *ca*. 1320; a barbed quatrefoil is used to frame the inscription on the back of this piece—see **Fig. 13b**. The quatrefoil motif was copied on a subgroup of early European astrolabes, notably #162 and the astrolabe under discussion. The Europeans developed the quatrefoil as a decorative feature on astrolabe retes far more than the Muslims had done—see, for a spectacular example, #290, made in England *ca*. 1300. Also Jewish craftsmen used the quatrefoil, even cruciform quatrefoils, as decoration on astrolabes.[140] Even the pre-expulsion seals of the Jews in Christian Spain were often in the form of, or had decoration in the form of, quatrefoils.[141] We shall return in **3.26** to the quatrefoil decoration of the cartouches on the back of the astrolabe under discussion. See also **XVII**.

11 The form of the star-pointers

Identical star-pointers are not found on any known astrolabe, Andalusī or medieval European. Those that come closest are found on the Northern French (?) astrolabe #300 from *ca*. 1300 (see **Fig. 14**), but they have larger holes, either single, double or triple, depending on the size of the pointer.[142]

12 The positions of the star-pointers

The position of Regulus, which being on the ecliptic serves as an indicator of precession and hence the date, is at Leo 22°, corresponding to *ca*. 1425. But this is insufficient to date the piece. The remaining star-positions point to a date in the range 1300-1350.[143] A more detailed investigation should be conducted.

13 The selection of stars

There are some 21 star-pointers. Western Islamic astrolabes tend to have some 27, following a clearly-defined tradition associated with the astronomer Maslama al-Majrīṭī (Madrid, *ca*. 1000).[144] The earliest known European astrolabe, #3042 from 10th-century Catalonia, has 20 unlabelled pointers,[145] and the astrolabe under discussion has 19 of these but is missing a Ophiuchi (often named *alhawi* on medieval European astrolabes) and has in addition

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Catalan Astrolabe", pp. 680-682, on the quatrefoil on the Catalan piece #162; and *idem*, "Astronomical Instruments between East and West", pp. 154 and 169, on some other examples. These instruments are also illustrated in King, *The Ciphers of the Monks,* pp. 384-390. The four papers listed as Tomba, "Astrolabi", A-D, deal with various Italian astrolabes with quatrefoil decoration. See now **XVII**.

[140] King, "Astronomical Instruments between East and West", pl. VIa on p. 154.

[141] See Friedenberg, "Spanish Jewish Seals", and the earlier publication by the same author, for various examples. Another is shown in *New York JM 1992 Exhibition Catalogue*, pp. 240-241 (no. 98).

[142] See Gunther, *Astrolabes*, II, pp. 477-478 (no. 300), and also G. Turner, "Carolingian Astrolabe", fig. 5 before p. 431.

[143] Information kindly provided by Burkhard Stautz.

[144] Kunitzsch, *Sternverzeichnisse*, pp. 17-18 (Typ III); and *idem* & Dekker, "The Stars on the Carolingian Astrolabe", pp. 656-658. On Maslama see the article "al-Madjrīṭī" in *EI*$_2$.

[145] Kunitzsch & Dekker, "The Stars on Carolingian Astrolabe", *passim*.

RIGORCA and ON9E. The Catalan astrolabe #162 from *ca*. 1300 has 20 stars, of which three are not found on this astrolabe.[146] A second star-table of al-Majrīṭī contains precisely 21 stars but only 13 of these are found on this piece.[147]

It is not unusual that the *selection* of stars represented on medieval astrolabes does not correspond to the various textual traditions that have been discussed by Paul Kunitzsch, and there is a lot more research remaining to be done on the data from instruments.[148]

14 The Latin names of the stars

The names of the stars on the rete are mainly Europeanised versions of the Arabic names, as was standard in the Middle Ages.[149] There are also several examples of Latin names, which we can associate with the introduction of the Latin translation of the *Almagest* of Ptolemy in al-Andalus in the 12th century.[150] But there are also four examples of bastardised Latin names, as if dictated by someone who could not read them properly; this is most unusual, but not entirely without precedent. It is certainly not unusual that the *names* actually used on astrolabe retes do not correspond to the names known from textual sources.[151]

There are some 21 star-pointers, and the stars seem to have been taken—appropriately enough—from the catalogue associated with the celebrated translator Johannes Hispalensis (Toledo, mid 12th century),[152] that is, Paul Kunitzsch's "Typ IV".[153] At least, all of the stars but one in Pegasus are found in his catalogue.[154] In this, the Latin names of 29 stars are presented, and Kunitzsch has suggested that the star-names may have been translated from those on an Andalusī astrolabe.[155]

The following table presents the original "Latin" names of the stars, with their numbers in Paul Kunitzsch's lists of astrolabe-stars,[156] the Arabic additions (in two layers), the Arabic or Latin forms from which these are derived, the number in Kunitzsch's "Typ IV", as well as the identification of the star and its modern designation.[157] I do not give the Latin names in the single 13th-century

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[146] King & Maier, "London Catalan Astrolabe", pp. 676-677 and 684-685.
[147] Kunitzsch, *Sternverzeichnisse*, pp. 15-18.
[148] See the problems discussed already in King & Maier, "London Catalan Astrolabe", pp. 684-685.
[149] On these see the numerous publications of Paul Kunitzsch. The forms found on astrolabes have not yet been subjected to serious study, but at least are documented in the forthcoming Frankfurt catalogue (n. 13 above). On the star-names on this piece see already King, "Star-Names on European Astrolabes", pp. 308-316.
[150] On Ptolemy see the article in *DSB*. For editions of the Arabic and Latin versions of his star catalogue see Kunitzsch, *Sternkatalog des Almagest*. See also Kunitzsch, *Sternverzeichnisse*, pp. 16-17, for a 12th-century list in which selected stars are already labelled in Latin.
[151] One needs only to compare the names found on any medieval astrolabe with those presented in the index to Kunitzsch, *Sternverzeichnisse*.
[152] See Sarton, *IHS*, II:1, pp. 169-172.
[153] Kunitzsch, *Sternverzeichnisse*, pp. 31-33.
[154] I refer to ε Pegasi, and there is also seems to be a problem with α and β Pegasi.
[155] *Ibid*., p. 31.
On the 27 astrolabe stars in the tradition associated with Maslama al-Majrīṭī (Madrid, *ca*. 1000) see n. 144 above. The star-tables associated with Ibn al-Zarqālluh—see Kunitzsch, "Two Star Tables from Muslim Spain"—do not have the enigmatic star *kaʿb al-faras* in Pegasus.
[156] The first number relates to the list in Kunitzsch, "Astrolabe Stars", pp. 158-161, representing the main Islamic tradition associated with the 10th-century Shiraz astronomer al-Ṣūfī (on whom see the article in *DSB*), and the second to the list in *idem*, *Arabische Sternnamen in Europa*, pp. 59-96, where their subsequent fate in the Latin European textual tradition is documented.
[157] For an overview of the origins of modern star-names see Kunitzsch & Smart, *Star-Names*.

No.	K-no.	Star-name (bold if original)	Arabic additions (as relevant)	Arabic or Latin name (A/L) name	Modern	Designation
1	**50/8**	PANTA **9**AITOS	***baṭn* • (illegible letter)**	**A *baṭn qayus***	**Baten Kaitos**	**ζ Ceti**
•		**dummy pointer (support symmetrically placed to the pointer for COR LEONIS (no. 7 below), as on various Western Islamic astrolabes)**				
2	**9/14**	ALGOL	***ghūl***	**A *al-ghūl***	**Algol**	**β Persei**
3	**24/18**	D**(A)**B**(A)**RAN	*dabrān*	**A *al-dabarān***	**Aldebaran**	**α Tauri**
4	**37/19**	RIGEL	***rijl al-jawzā***	**A *rijl (al-jawzāʾ)***	**Rigel**	**β Orionis**
5	**39/23**	ALABOR	***ʿabūr***	**A *al-ʿabūr***	**Sirius**	**α Canis maioris**
6	**40/25**	**9**OMIZA	*ghumayṣa*	**A *al-ghumayṣāʾ***	**Gomeisa**	**α Canis minoris**
7	**26/30**	**9**OR LEO**(NIS)**	***asad***	**L *cor leonis***	**Regulus**	**α Leonis**
8	**- /28**	RIGORCA	***rijl***	**A *rijl* + L *ursae* (!!)**	**-**	**μ Ursae maioris**
9	**43/36**	**9**ORUUS	***ghurāb***	**L *corvus***	**- (see below)**	**γ Corvi**
10	**29/39**	SPI**9**A	***aʿzal***	**L *spica***	**Spica**	**α Virginis**
11	**1/41**	ALRAME**(CH)**	**illegible**	**A *(al-simāk) al-rāmiḥ***	**Arcturus**	**α Boötis**
12	**2/45**	FE**9**A	***fakka***	**A *(al-)fakka***	**Alphecca**	**α Coronae borealis**
13	**12/- (!)**	ON**9**E	*al-ḥayya*	**A *ʿunuq al-ḥayya***	**Unukalhai**	**α Serpentis**
14	**30/48**	**9**OR S**9**ORPI**(ONIS)**	***qalb***	**L *cor scorpionis* A *qalb al-ʿaqrab***	**Antares**	**α Scorpionis**
15	**4/53**	UEGA	***wāqiʿ***	**A *(al-nasr) al-wāqiʿ***	**Vega**	**α Lyrae**
16	**6/56**	RADF	***rid[f]***	**A *(al-)ridf***	**Deneb**	**α Cygni**
17	**13/54**	ALTAIR	*al-ṭāyir*	**A *(al-nasr) al-ṭāʾir***	**Altair**	**α Aquilae**
18	**32/59**	**9**AUD:**9**OARI **(error for CAUD(A) CAPRI)**	***-r-w* (??)**	**L *cauda capricorni***	**Algedi**	**δ Capricorni**
19	**- / -**	**9**ABI	**-**	**A *kaʿb a(l-faras)***	**-**	**κ Pegasi**
20	**18/63**	OMER**9**I	***mankib faras***	**L *(h)umerus equi***	**Scheat**	**α Pegasi**
21	**35/4**	D**(E)**N**(E)**P **9**AITOS:	***d(hanab)***	**A *dhanab qayṭus***	**Deneb Kaitos**	**ι Ceti**

Vienna manuscript used by Kunitzsch in his edition of the table of "Typ IV". There is a 14th-century copy in Oxford in which the Arabic equivalents are given alongside the Latin names,[158] but none of these lists casts any light on the problems associated with the names on our rete, which do not correspond to those in Kunitzsch's "Typ IV" anyway.

Some comments on the more unusual names are in order. (See already the remarks in **3.3** on vernacular influences.) Firstly, some forms derived from the Arabic:

- ❖ PANTA (no. 1) from *baṭn*, "belly (of the whale)". This form is found already in a 10th/11th-century Latin source, as well as in a 13th-century copy of the astrolabe treatise of Pseudo-Messahalla, parts of which are translated from a treatise by the Andalusī astronomer Maslama al-Majrīṭī.[159]
- ❖ D(E)N(E)P / D(A)N(A)P (no. 21) from *dhanab*, "tail (of the whale)". The more usual form is DENEB.[160]
- ❖ **9**OMIZA (no. 6) from *(al-)ghumayṣāʾ*, which means something like "the one with eyes impaired by weeping" (compared with Sirius). This form is not attested in the manuscript tradition, which tends to prefer (AL)GOMEI/YZ/SA.[161] #162 has ALGOMIC.
- ❖ ON**9**E (no. 13), a very vernacular derivation from *ʿunq* or *ʿunuq (al-ḥayya)*, "neck (of the serpent)", is not known to be attested elsewhere. The early modern (17th-century) forms are UNUK or UNK, usually followed by ALHAY or variants thereof, which are closer to the Arabic.[162] The final E of ON**9**E is probably a remnant of the Arabic article *al-*.
- ❖ UEGA (no. 15) from *(al-)wāqiʿ*, "falling (eagle)". This corresponds to WEGA in some textual sources.[163]
- ❖ RADF (no. 16) from *(al-)ridf*, "the person riding on a horse behind the main rider", is not known either from the textual tradition or from any known medieval astrolabe. The more common names are RIDF and REDF, corresponding more closely to the Arabic,[164] and #162 has ALREDAF.
- ❖ **9**ABI (no. 19), pronounced KABI, appears to be derived from the Arabic *kaʿb al-faras*, "the ankle of the horse (Pegasus)", κ Pegasi. This star is not otherwise known from European astrolabes or star-lists. Indeed it is not a standard astrolabe-star, although it does appear on some of the astrolabes of the prolific Muḥammad ibn Fattūḥ al-Khamāʾirī of Seville *ca*. 1225.[165]

Then some forms based on Latin:

- ❖ **9**AUD: **9**OARI (no. 18) is an error for CAUD(A) CAPRI(CORNI), with COARI apparently from ACOARI (from Aquarii),[166] rather than from CAPRI. The colon is used as a separator

[158] A photo is to be found in Gunther, *Early Science in Oxford*, II, p. 205.
[159] See Kunitzsch, *Arabische Sternnamen*, p. 67, no. 8.
[160] *Ibid*., p. 66, no. 4.
[161] *Ibid*., pp. 73-74, no. 25.
[162] *Ibid*., p. 217, no. 196. For some reason this star is not listed by Kunitzsch as an astrolabe-star.
[163] *Ibid*., p. 81, no. 53.
[164] *Ibid*., p. 82, no. 56.
[165] For example, on #130—see Gunther, *Astrolabes*, I, pp. 276-277 (no. 130), and Kunitzsch, *Sternverzeichnisse*, p. 31, n. 2. On al-Khamāʾirī see Mayer, *Islamic Astrolabists*, pp. 64-66.
[166] Aquarius does not, of course, have a tail (*cauda*), though see Burnett, *Studies*, XVII, p. 120, where he is given a *cadacauda* in a 12th-century source.

(also at the end of no. 21); it was not uncommon for abbreviations such as HU: EQUI (for HUMERUS EQUI—see below) to be used for star-names engraved in restricted space on astrolabe retes.

- ❖ OMER9I (no. 20), pronounced OMERQ(U)I / OMERKI, seems to derive from OMER (E)QUI, a vernacular form of the Latin *humerus equi*, "the shoulder of the horse", α Pegasi.

Finally, one very remarkable name that seems to be based on a mixture of Arabic and Latin:

- ❖ RIGORCA (no. 8), pronounced RIGORSA or RIGORÇA, may be from RIG(EL) ORSA(E), a combination of Arabic and vernacular Latin ("correctly", *rijl ursae*), μ Ursae maioris.[167] The proper Arabic form would be *rijl al-dubb*, "the (back) leg of the Bear". The precise Latin equivalent is not specifically stated in the Latin translation of Ptolemy's star-catalogue,[168] and medieval European astrolabists seem to have had some problems with the star.[169]

15 The Arabic names of the stars

With regard to the four Arabic star-names added by Masʿūd, we note the following:

- ❖ *dabrān* (no. 3) with a *sukūn* or zero-vowel on the *r* (= *rāʾ*), clearly intended for the *b* (*bāʾ*); the standard name is *(al-)dabarān*.[170] This form *dabrān* is Spanish Arabic, for there the second vowel of two successive internal short syllables can be suppressed.[171] The usual medieval European forms are ALDEBARAN/M, although the astrolabe under discussion has DBRAN, perhaps for D(A/E)BRAN, perhaps for D(A/E)B(A)RAN, and ALDEBRAN is attested in Geoffrey Chaucer's treatise on the astrolabe and on one 14th-century English astrolabe (#457).[172]
- ❖ *ghumayṣa* (no. 6), correctly *ghumayṣāʾ*, from which the Latin form is derived, is the Western Islamic name, the star being called *al-shiʿrā al-shaʾāmiya* in the Islamic East.[173] The form *ghumayṣa* is probably to be regarded as a Spanish Arabic simplification of the classical form.
- ❖ *al-ḥayya* (no. 13), with a *sukūn* on the *l* (= *lām*), which is correct but superfluous, and a *shadda* on the *y* (= *yāʾ*), which is appropriate, is abbreviated from *ʿunuq al-ḥayya*.[174]

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[167] *Ibid*., pp. 74-75, no. 28.

[168] See Kunitzsch, *Sternkatalog des Almagest*, II, p. 38, no. 21.

[169] It is not amongst Paul Kunitzsch's list of astrolabe stars (*Arabische Sternnamen in Europa*, pp. 59-96), but is listed as *pes ursi* (*sic*) in one medieval star-table (*idem*, *Sternverzeichnisse*, p. 32, no. 13). See also *Chicago AP Catalogue*, I, p. 159, where it is not to be found in the list of all stars featured on the astrolabes in the collection. On this star see now Kunitzsch, "Three Dubious Stars", pp. 68-69.

[170] Kunitzsch, *Sternnomenklatur der Araber*, p. 51, no. 69.

[171] Article "al-Andalus, x: Spanish Arabic" in *EI*₂, by G. S. Colin, especially p. 502b. I did not find any examples of this phenomenon in Corriente, *Spanish Arabic*, but words of the form CaCaCān are not common. On the other hand Corriente (*ibid*., p. 64) notes that in an open syllable followed by a closed one the second vowel is stressed. In passing we note the form Çuléyman for Sulaymān (*ibid*., p. 65).

[172] Kunitzsch, *Arabische Sternnamen in Europa*, p. 47 and p. 70, no. 18.

[173] *Idem*, *Sternnomenklatur der Araber*, p. 112, no. 290a.

[174] See n. 162 above.

- *al-ṭāyir* (no. 17), with a *y* (= *yāʾ*) rather than a carrier for a *hamza*, an acceptable Middle Arabic form of *al-ṭāʾir*.[175]

Note that the stars have been selected because each one is in a different quadrant of the heavens, so that at night, in theory, at least one is always visible. Another astrolabe (#169), from Italy *ca.* 1300, has only four stars on its rete, one each quadrant: see **XIIId-2.4**.

In the case of the second layer of Arabic star names, scratched near their "Latin" equivalents, the hand is totally different from that of Masʿūd. It seems inconceivable anyway that he would have made these messy additions to his own astrolabe. Thus it seems reasonable to postulate a second Arabic hand.

These additional names are given in the Table. Several are difficult to see and not a few difficult to read. No equivalent name has been given for **9**ABI (no. 19), doubtless because this was not a standard astrolabe-star and the Latin name seemed so strange; one name (no. 11), scratched around the hole at the base of the star-pointer, is illegible; and another (no. 18: *ṭ-r-w*) makes no sense.

16 The astronomical markings on the three original plates

The latitudes on the three plates that belong together (hereafter P1-P3) serve Jerusalem and Reims (see **3.8**) as lower and upper limits. The remaining latitudes span the range 40°-45°, bounded by Toledo in the south and Vienne (or maybe Lyon) in the north. These latitudes can act as a guide to the provenance of the instrument.[176] We may be confident that the astrolabe was made either in Central or Northern Spain or Southern France, favouring the former possibility. See further **3.19**.

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[175] *Ibid.*, p. 86, no. 194a.

[176] See n. 36 above. For comparison we note the latitudes on three medieval Catalan pieces (see further King, "Oldest European Astrolabe", pp. 372-376, and King & Maier, "London Catalan Astrolabe", pp. 677 and 690-695) as well as the unique astrolabe with Judaeo-Arabic inscriptions (see *London Khalili Collection Catalogue*, II, pp. 214-217, no. 124):

First, #3042 has astrolabic markings for latitudes 36°, 39°, 41;30°, 45° and 47;30°. Only the third latitude is associated with any locality, namely, "ROMA ET FRANCIA", which refers to Rome and Catalonia, the latter where the instrument appears to have been made. What the maker had in mind for the other latitudes we can only speculate, and it is difficult to know whether a Graeco-Roman tradition or the Islamic tradition is more relevant: 36°—[Rhodes / "Africa" / 4th climate]; 39°—[Sicily / Naples / boundary between 4th and 5th climates]; 45°—[Vienne / Po Valley / 4th climate]; 47;30°—uncertain, one possibility is Heraclea Pontica on the Black Sea. See further King, "Geography of Astrolabes", pp. 11-12, now in **XVI-5**.

Second, #162 has plates for latitudes 32;30°, 38;30°, 39;40°, 41° and 42°, with no place-names. These might serve Jerusalem, Cordova, Valencia, Barcelona/Rome (?), and Pamplona/Gerona (?). This piece was probably made in Valencia.

Third, #416 has plates for 31°—Damietta, 32°—Jerusalem, 33°—"Africa", *i.e.*, the Maghrib, 34°—Tripoli, 35°—Ceuta, 38°—Sicily, 39°—Valencia, 40°—Segovia, 41°—Barcelona, 42°—Pamplona, 43°—Macedonia, 44°—Genoa, 45°—Milan, 46°—no locality specified. This piece was made in Catalonia, therefore only Valencia and Barcelona come into consideration.

Fourth, #3915, the astrolabe with inscriptions in Judaeo-Arabic, has plates for: 29°—Sijilmasa, 30°—Cairo, 31°—Marrakesh, 32°—Jerusalem, 37°—Tunis, 37° (?)—Seville, and 38°—Cordova. This information is more of academic than practical interest because the markings on the plates do not correspond to these latitudes. It is not clear whether the instrument was made in al-Andalus or the Maghrib.

The dangers of trying to identify which locations astrolabe-makers had in mind, when we know only the latitudes they used for their plates, are well illustrated by the French quatrefoil astrolabe #546. Here the localities are mentioned and not a few are surprising: 32°—Jerusalem; 36° "Affrica" [= Tunisia]; 42°—Rome; 45°—Montpellier; 47°—"CATVR" (unidentified, perhaps Tours); 48°—Paris; 53°—no location specified. On the French quatrefoil astrolabe #3058 the remaining original plates serve: 37°—Carthage; 38°—Tunis; 41°—Armenia; 42°—Rome; 45°—Cremona; and 49°—Paris. There is a replacement plate for 52°—London and 53°—Lincoln.

The lightly-engraved initial horizons for 45° on the plates for latitudes 32½° and 43° suggest that the maker started working on them and changed his mind about which latitude he really wanted the plates to serve.[177]

There are occasional problems with the markings, namely:

32½° circle for the winter solstice;
40° azimuth circle at 10° to the left of the upper meridian; one azimuth circle extended too far towards zenith;
42° circle for the winter solstice; uppermost altitude circle; altitude circle for 66°;
43° uppermost altitude circle;
45° circle for the equinoxes has been engraved double; uppermost altitude circle;
49½° right-hand side of the prime vertical, that is, the azimuth circle passing through the east- and west-points.

These may be compared with the markings on P4 where a different maker has become unstuck—see **3.21**. In addition, however, on these three plates the construction of the azimuth curves is non-standard—see **3.17**.

On P1 and P2 there is a small hole at the intersection of the meridian with the circle for the winter solstice. This is not uncommon on medieval astrolabe plates.[178] On P3 the hole is at the right hand intersection of the horizontal diameter and the winter solstice circle for 43° and the left-hand intersection for 49½°, almost as if the engraver made the hole, then went ahead with the rest of the markings forgetting about the hole. There is no such hole on P4.

17 The construction of the azimuth circles on the three original plates

On each of P1-P3 there are two rows of eight equi-spaced construction marks between the intersections of the circle for the equinoxes with (1) the meridian below the horizon and (2) either side of the horizontal diameter. The azimuth circles, when produced below the horizon, pass through these points. This indicates that the points were used for the construction of the azimuth circles (which also all pass through the zenith). The centre of the prime vertical, visible on the meridian below the horizon, is then determined, and the centres of the other azimuth circles, also visible, would have been determined as the points on the perpendicular to the meridian through this point that are equidistant from the zenith and the appropriate point on the construction lines. Such a procedure is not only approximate and not much simpler than the rather cumbersome standard method (as used by Masʿūd on P4), it is also wrong. Although the azimuth circles are not noticeably differently placed with regard to the horizon, on either side of the meridian above (*i.e.*, to the south of) the zenith, they are wildly divergent from reality.

Now this procedure is unknown to the modern literature, and no medieval texts describing it are

[177] This calls to mind a North Italian astrolabe dated 1420 (#4523) on which all the plates are for latitude 45°, serving the Po Valley but also the middle of the 6th climate, even though they are labelled for a series of different latitudes. See further Stautz, "Ein Astrolab aus dem Jahr 1420".

See *Nuremberg GNM 1992-93 Exhibition Catalogue*, II, pp. 589-592 (no. 1.77), especially fig. 1.77.3, for a horizon for *ca*. 49° on astrolabic markings for *ca*. 46;30° on a German instrument dated 1468 (#550).

[178] Documentation of this phenomenon would be difficult. The purpose of the holes is unclear.

currently known either.[179] It is, however, clearly related to a procedure outlined in a 13th(?)-century manuscript of an anonymous Spanish Latin treatise on the construction of the astrolabe.[180] No other medieval astrolabes are known to bear such construction marks, but since the procedure was hitherto unrecorded, no such markings have ever been sought on astrolabe plates.[181]

Note added after completion of this version: In May, 2004, I saw an early-18th-century Maghribi astrolabe (#4300) that had a series of plates for various latitudes, including the distinctive 33;40° for [Fez], as well as 21° for Mecca and 25° for Medina.[182] A set of longitudes of localities between Fez and the Holy Cities is engraved on the mater. One of these localities is Constantine, on the Algerian littoral, which explains the curious "41 41" engraved on one of the plates: this is clearly Constantinople with latitude 41°, and the maker has made a mistake. More to the point, whilst all of the other plates are constructed normally, this particular one has azimuth circles constructed in the same way as the plates on the Spanish astrolabe.

Furthermore, on each of the original plates on the Spanish astrolabe there is a set of points on what appears to be part of an altitude curve at about 30° below the horizon on the left-hand side of the meridian (most clearly visible on the plate for 43°). The purpose of these markings has not been established.[183]

18 The plates for Jerusalem and Reims

The inclusion of Jerusalem, common on medieval European astrolabes, may have been *pro forma*, imitating the presence of Mecca on Islamic astrolabes. If the maker was a Christian, there may have been in his mind the eventuality that the instrument might be used by a pilgrim or by a crusader.[184] And if he was a Jew, even one converted to Christianity, a plate for Jerusalem would have been doubly appropriate. Such a plate is found on the Judaeo-Arabic astrolabe #3915, but not on the later Jewish astrolabes (#158, #159 and #3906)—see **3.20**. In addition we note that 32;30° for Jerusalem is not an Islamic value,[185] but it is found on the Catalan astrolabe #162.[186]

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[179] Various procedures, all exact, are described in Berggren, "Construction of Azimuth Circles", and, most recently, Lorch, "Rudolf of Bruges on the Astrolabe", pp. 90-91. See also Michel, *Traité*, pp. 53-56, and Hartner, "Astrolabe", A, pp. 296-298.

[180] Edited in Millás Vallicrosa, *Traducciones orientales*, pp. 318-319 (I owe this reference to François Charette). On the problematic attribution assumed by Millás, see Kunitzsch, "Astrolabe Treatise Ascribed to Messahalla", p. 49, especially n. 35. The procedure and this text should be investigated further.

[181] In the same way it was a surprise to find that the shadow squares on two 14th-century Northern French astrolabes (#198 and #202) were constructed by an approximate procedure. There the procedure is likewise incorrect and the divergence even more obvious. See further King, *The Ciphers of the Monks*, pp. 416-417.

[182] Described and illustrated in *Christie's London 30.06.2004 Catalogue*, pp. 26-27 (lot 149). See also the text to n. 58 in **XVI**.

[183] They are not related to the unusual circles for twilight that are found, for example, on the 14th-century Picard piece #202. On each of the plates of that piece we find an altitude circle below the horizon which is tangential to the equinoctial circle, and whilst the approximation to the conditions of dawn and nightfall is reasonable for the latitude of, say, Paris, for lower latitudes the error is considerable. See further King, *The Ciphers of the Monks*, pp. 412-414 and 416.

[184] On the earliest European astrolabe we find Rome rather than Jerusalem, but not necessarily because Rome was important to the maker, but rather possibly because the instrument seems to bear traces of a *Roman* tradition of astrolabe-making. See n. 207 below.

[185] Kennedy & Kennedy, *Islamic Geographical Coordinates*, pp. 160-161.

[186] See n. 176 above and also King & Maier, "London Catalan Astrolabe", p. 692.

One possible implication is that some Crusader took the trouble to measure the latitude of Jerusalem, although his value 32;30° is less accurate than the standard Islamic values 31;50° and 32°0 (the correct value is 31°47′). Another is that this was a compromise between two Islamic values, 32;0° and 33;0°.

The inclusion of a plate for 49;30°, too high for Paris,[187] is surprising but can be explained. Various values were used for Paris in the Middle Ages, and they all lie between 48° to 49°.[188] On the other hand Reims is given latitude at 49;20° in a 15th-century English geographical table (the correct value is 49°15′).[189] In earlier sources it is given a latitude far too low, but is identified as *sedes regis francorum*, "the seat of the king of the French",[190] and that is why it is featured here. More specifically, however, in 1234 Count Thibaud IV of Champagne had become king of Navarre, and in 1284 Countess Jeanne of Champagne and Navarre married Philippe le Bel, so that there were strong ties between Navarre and Reims.[191] This is, alas, not sufficient evidence to assume an origin for the astrolabe in Navarre, although Jewish craftsmen were active in such centres as Pamplona and Tudela. If the astrolabe was made there it might have ended up in the hands of the *mudéjar* Masʿūd further south.

19 The other localities served by the original plates

It was usual for medieval astrolabe-makers to prepare plates for a span of latitudes on either side of the latitude of their own location.[192] Occasionally they did later historians the favour of marking the name of that locality, but alas that is not the case here. The three plates serve latitudes:

$32^1/_2$	42
40	45
43	$49^1/_2$

In the light of these three plates alone the latitudes 42° and 43° could be considered the most reliable pointers to the provenance: in some medieval geographical tables both values are associated with Narbonne (and nowhere else),[193] but this city is too far north and not where one would expect to find an Arab engraver. But 42° might also have been intended for Barcelona (as on #416), although it is too high and linguistic considerations speak against a Catalan provenance for our

[187] In A. J. Turner, "Astrolabe exceptionel" / "Exceptional Astrolabe", it is assumed this plate is for Paris, adducing #190, an astrolabic plate supposedly for latitude 49;30°, in support of this. However, the latitude engraved on that plate is 48;50° not 49;30°.

[188] North, *Horoscopes and History*, p. 194. Where we find 49°, as on the 14th-century French astrolabe #3058, and on the 15th-century French additions to the 14th-century Italian astrolabe #548, it is most probably rounded from 48;50°, or from another common value, 48;48°. The former is given by Jean Fusoris *ca*. 1400 in his treatise on the construction of the astrolabe—see Poulle, *Fusoris*, p. 100.

[189] *Ibid*.

[190] Reims, identified only as *sedes regis francorum*, is at 45;50° in two 12th-century sources, the *Toledan Tables* and the *Marseilles Tables* (Ptolemy had 45;30°)—see Kennedy & Kennedy, *Islamic Geographical Coordinates*, p. 285.

[191] See *Paris GP 1998 Exhibition Catalogue* on the fates and fortunes of Philippe and his sons.

[192] Andalusī astrolabes do not accord with this rule, not least because to the north lay regions inaccessible and undesirable to their Muslim makers. Thus, for example. #1099, made in Saragossa in the late 11th century, has 11 sets of markings for latitudes between those of Mecca and Saragossa, but nothing beyond.

[193] North, *Horoscopes and History*, p. 193.

piece. It could also have been intended for Saragossa, whose latitude was taken as 41;30° (as on #1099, actually made in Saragossa, #117, #118, *etc*.) or 42° (as on #110, #3650, #2572, *etc*.), or even 43;30° (as on #116). The composite European astrolabe #191 has 41° for Saragossa. In that city, as well as in Toledo (see below), there were Jewish metal-workers in the Middle Ages.[194] Burgos is another possibility for latitude 42°. A solitary 11th-century plate in an Andalusī astrolabe dated 638 H [= 1240/41] (#154) has 40° for Toledo and 42° for Burgos; no other Islamic astrolabes have markings for Burgos.[195] In a 15th-century Spanish gazetteer the latitude of Burgos is given as 43;4°.[196] Another possible choice for latitude 43° would be Pamplona, capital of Navarre, although on the medieval Catalan astrolabe #416 it is put at latitude 42°.[197]

Now the fourth plate is not original and it may be that an original fourth plate bore markings for, say, 38;30° (for Cordova, in Christian hands since 1236 and often featured on early European astrolabes, *e.g*. #162) and 44° (if only for the sake of completeness). This would fit nicely into the arithmetical organization of the latitudes on the plates, thus:

$32^1/_2$	42
[$38^1/_2$	44]
40	45
43	$49^1/_2$

In this case, latitude 40° would come into consideration as a pointer to provenance, which would most likely be Toledo. This has the advantage that it was the main centre of Jewish activity in metalwork in the whole of Spain.[198] The parameter 40° was the only serious latitude for Toledo in Islamic geographical tables,[199] possibly rounded from the value 39;52° (accurate to the minute) found aleady on some 11th-century Andalusī astrolabes,[200] and in the 15th century the value 39;53° or 39;59° is given in a Christian Spanish source.[201] Another possibility for the original fourth plate would have been the latitudes 37;30° (for Seville, recaptured by the Christians in 1248) and 38;30° (for Cordova); this again would point to a slightly higher latitude for the provenance, say, 40° for Toledo. If the hypothetical original plate had borne markings for, say, 36° (Almería) and 38;30° (Cordova), both standard on medieval Western Islamic astrolabes, Masʿūd might have resisted the temptation to engrave a new plate.

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[194] See n. 9 above.

[195] In *Chicago AP Catalogue*, I, pp. x-xi, the astrolabe itself is stated—presumably citing a one-line description from the 1920s—to be from Toledo.

[196] Cátedra & Samsó, *Astrología de Enrique de Villena*, p. 94.

[197] See n. 176 above.

[198] See nn. 9 and 194 above.

[199] See Kennedy & Kennedy, *Islamic Geographical Coordinates*, pp. 357-358;

[200] In King, "Geography of Astrolabes", pp. 16-17, I claimed that 39;52° was one of the values attributed in the 13th-century *Libros del saber de astronomía* to the Andalusī astronomer Ibn al-Zarqālluh in 1067. This turns out to be nonsense: see the preliminary remarks to **XVI**.

[201] Millás Vallicrosa, "Astrología de Enrique de Villena", p. 416: "40 menos 7 min.", and Cátedra & Samsó, *Astrología de Enrique de Villena*, p. 94: "40 menos un minuto".

20 The Hebrew inscriptions on the three original plates

The latitudes of the six sides of the three original plates are scratched in Hebrew alphanumerical notation at the bottom rim of each side. They are expressed sexagesimally (in degrees and minutes) because in Greek, Arabic and Hebrew this kind of notation alone is used for sexagesimal numbers and fractions.[202]

The positioning of these scratches seems to indicate that they were added in the course of construction.[203] In other words, one of the persons involved in the construction was a Jew.

The number of astrolabes with original inscriptions in Hebrew characters is few indeed. The earliest one is that with inscriptions in Judaeo-Arabic (#3915), dating from *ca*. 1300. Then there are three astrolabes with inscriptions in Hebrew, clearly from the same milieu, probably Italian, possibly Bologna,[204] and apparently dating from *ca*. 1400: #158 (London), #159 (Chicago), #3906 (Paris, private collection). The back of another astrolabe #621 (Munich) may come from the same tradition. Finally, there are Hebrew additions to two 11th-century Andalusī astrolabes:

- ❖ #2572 (a replacement rete with Hebrew inscriptions), and
- ❖ #116 (additions to the solar and calendar scales as well as the plates for Toledo and Cordova);

to an Italian astrolabe from *ca*. 1300:

- ❖ #4509 (Hebrew names of the signs and the months);

and to a 14th-century English astrolabe:

- ❖ #293 (owner's mark in Hebrew on the throne and Hebrew abbreviations for zodiacal signs and month-names on the back).

21 The fourth plate

P4 is slightly thicker than each of P1-P3 (see **2.10** and **2.12**). Although the markings "look" as if they are by the same maker, not least because the divisions are the same and the azimuth circles do not extend beyond altitude 78°, we note first that:

(1) P4 has no markings in Hebrew, such as are found on P1-3.

(2) P4 has no small hole at the intersection of the meridian with the circle for the winter solstice, such as are found on P1 and P2, and in a different position, on P3.

In addition, there are various differences in the construction marks, notably:

(3) The maker of P4 marked a short incision at some of the points where the altitude circles cut the meridian; these marks are lacking on P1-3.

(4) On both sides of P4, the centres of the azimuth circles are clearly visible on a horizontal line below the horizon; on P1-3 there are traces of a different, approximate construction, although the centres of the azimuth circles are also present—see **3.17**.

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[202] On Hebrew alphanumerical notation, see the references in n. 49 above. On sexagesimal notation in general see, for example, Berggren, *Episodes*, pp. 39-48.

[203] Several astrolabes have interpretations of or corrections to the latitudes indicated just below the inscriptions mentioning the latitudes—see, for example, King, "Astronomical Instruments between East and West", p. 153, fig. Vc. The custom of marking *batch numbers* near the pegs on plates was followed by Georg Hartmann in Nuremberg in the early 16th century—see, for example, *Nuremberg GNM 1992-93 Catalogue*, II, pp. 593, 594c and 596a.

[204] The only clue to provenance on the four astrolabes is that one of the plates on #159, albeit a poorly-made piece lacking the quality of the others, bears the name Bologna (and also Paris) in Hebrew—see *Chicago AP Catalogue*, I, pp. 58-60 (no. 7). The three pieces are discussed together in Goldstein, "Hebrew Astrolabe", but a more detailed comparative study would be worthwhile. On the dating see *ibid*., pp. 156-157.

(5) On P1-3, below the horizon, there are short lines to mark the divisions on the circles corresponding to the equinoxes and solstices, as an aid in the construction of the curves for the seasonal hours; these are lacking on P4.
(6) On P4 there are several azimuth curves which are slightly too long or slightly too short at the horizon; this is not the case on P1-3.
(7) On P4 two of the hour-curves on the side for Mecca are duplicated; there are no such problems with any of the hour-curves on P1-3.

In general, the markings on P4 are slightly less carefully executed than those on P1-3, but, as noted in **3.21**, the latter are not without occasional problems. On P4 there are also problems with the curve for the *ẓuhr* on the side for Algiers, which has been duplicated along most of its length.

A metal analysis could provide definitive proof whether the fourth plate came from the same workshop as the other three. The visual evidence suggests that at least the raw plate did.

See **4.5** on the latitudes used by Masʿūd for Mecca and Algiers.

22 The times of Muslim prayer on the plates for Algiers, Mecca and Jerusalem

Markings for the times of Muslim prayer are standard on Andalusī and Maghribi astrolabe plates: see **Figs. IV-7.3** and **X-4.5.1**. The times of the prayers shortly after midday and mid-afternoon prayers (*ẓuhr* and *ʿaṣr*) are defined by shadow-lengths and they are marked by special curves amidst those for the seasonal hours. In order to draw them one needs only to know the times of the prayers at the equinoxes and solstices, mark these on the corresponding base-circles and construct the arc of a circle through the three points. The times of the night-time prayers are at nightfall and daybreak, defined when the sun has a certain angle of depression below the horizon, usually taken as 18° by Andalusī astronomers. The altitude circle for -18° can be drawn, but it is easier to mark the altitude circle for +18° in a special way and to use the point opposite to the sun on the ecliptic ring. In the case of the astrolabe under discussion, as on most Andalusī astrolabe plates, the latter procedure has been adopted.

On the plate for Algiers, there are thus two curves serving the daylight prayers and there are fish-bone markings on the altitude circle for 18° between the solstices. None of these markings is labelled.

On the plate that serves the latitude of Mecca, only the altitude circle for 18° is marked, and there are no curves for the daylight prayers. Furthermore, it should be noted that not a single known European astrolabe has astronomical markings specifically stated to be for the latitude of Mecca, even though some such instruments have extensive ranges of latitudes from the equator to the northernmost inhabited regions.[205]

On the plate serving the latitude of Jerusalem, the altitude circle for 18° has been marked in a similar way, but not necessarily by the same hand. There are no additional markings for Muslim prayer-times on any of the other original plates. If Masʿūd was indeed active in Toledo or Saragossa, one might have expected him to have added markings on the appropriate plate.

[205] The 14th-century French (?) piece #2041 does have a plate for latitude 22°, but no localities are mentioned on any of the plates, which serve 10 latitudes between 22° and 48°.

We have noted that there are no labels on any of these prayer-curves, even though it was standard practice in Andalusī and Maghribi astrolabe-making to label such curves. Are we here witnesses to yet another attempt to dissimulate and not to draw attention to Masʿūd's religion? See further **4.4**.

23 The scales on the back

The presence of a calendar and solar scale on the back is precisely what we should expect on a medieval European astrolabe.[206] This tradition was adopted from earlier Western Islamic astrolabes, on which such scales appear already in the 10th century, if not before. And that earlier tradition seems to be inspired by a Roman tradition, if the evidence provided by the 10th-century Catalonian astrolabe (#3042) has been correctly interpreted.[207]

Yet there was also an Eastern Islamic tradition of such scales. First, the great scientist al-Bīrūnī (Central Asia, early 11th century) mentions an astrolabe bearing the names of the Byzantine months.[208] And second, a few astrolabes from 12th- and 13th-century Syria, Egypt and the Yemen have such scales, either for the Syrian months (for example, #103, #140 and #4029) or for the Coptic months (for example, #106).[209]

Since the front of the astrolabe under discussion is to all intents and purposes European in execution if not in style, we may assume that the scales on the back were originally intended to be engraved with the appropriate Latin forms of the names of the zodiacal signs and months. Masʿūd engraved the Western Islamic forms of the European month-names. These were used by the Arabs in al-Andalus in the 14th century alongside the Muslim months; often dates are given in both calendars.[210]

24 The dates of the equinoxes and solstices

The dates of the equinoxes and solstices, namely:

III $13^1/_3$ VI $15^3/_4$ IX $16^1/_2$ XII $14^1/_3$

correspond, at least for the equinoxes, to *ca*. 1200, but this should not be taken too seriously for the purpose of dating the astrolabe.[211] For comparison, we note that:

a) the Catalan astrolabe #3042 of supposedly *ca*. 975 has the vernal equinox at III 15;
b) an early Spanish or French astrolabe #161 (present location unknown) also has III 15;
c) an early medieval astrolabe of uncertain provenance #420 has III 14;
d) the Catalan astrolabe #162 of supposedly *ca*. 1300 has III 12;
e) the other Catalan astrolabe #416 of the same supposed date has III 11.5; and

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[206] Thus, when there is no such scale on a medieval European astrolabe, we may suspect that we are dealing with a copy of an Islamic instrument: see **XIIId-6** on #169.

[207] King, "Oldest European Astrolabe", pp. 384-385. The first paragraph on p. 384 should have been preceded by the words "Added in Proof".

[208] On al-Bīrūnī see the article in *DSB*. For the quote see King, "Oldest European Astrolabe", p. 376, n. 39.

[209] See n. 127 above.

[210] For some examples see van Koningsveld, "Arabic Manuscripts from Christian Spain", A, pp. 85-87.

[211] This dating is based on a computer-generated table of dates of the equinoxes and solstices for each 100 years from 0 to 2000 prepared by Dr. Benno van Dalen, Frankfurt. In A. J. Turner, "Astrolabe exceptionel" / "Exceptional Astrolabe", the vernal equinox is associated with the second quarter of the 14th century. On the problems associated with this kind of dating see the studies cited in n. 37 above.

f) the astrolabe of Petrus Raimundus #3053 dated Barcelona, 1375 has III 12.
Only the last of these instruments is actually dated, and the dates assumed for the others may be in error by as much as ±50 years.

25 The use of silver
Silver is used for the buttons at the base of star-pointers as well as the handles on the retes on several 11th-century Andalusī astrolabes, as well as on the unique astrolabe with Judaeo-Arabic inscriptions. In the holes on the star-pointers here there is no trace of silver, thus the holes are purely decorative.

Only one medieval European astrolabe has any inlaid silver or any kind of cartouches for inscriptions. This is #213, a piece of uncertain date and provenance: on the back of this, illustrations of the zodiacal signs are inlaid in silver. Unfortunately, however, the location of this piece is unknown and no photos of the back are known to exist.[212] Also, no known astrolabe from the Islamic West has inlaid silver cartouches, or indeed any kind of cartouches, for the inscriptions,[213] other than #4182, made in Fez in 719 H [= 1319/20], where the signature on the back is enframed in a barbed quatrefoil (see **Fig. 13b**). Another piece, #4217, made in Granada in 886 H [= 1481/82], has silver inlay, this in decorative single-leaf-forms on the front of the throne (in addition to the silver knobs on the rete and silver buttons on the star-pointers).[213a] A substantial number of surviving astrolabes from Ayyubid and Mamluk Egypt and more especially Syria are inlaid with silver, in fact, some eight out of a total of thirteen known pieces from Egypt or Syria during the period 1150-1300.[214] A spectacular example is #137, an astrolabe by al-Sahl al-Nīsābūrī, made in Syria between 1180 and 1280 (see **XIVb-2**). Here the circus-figures decorating the rete are inlaid with silver, and the star-names are engraved on the silver. Two more are the splendid instruments of ʿAbd al-Karīm al-Miṣrī, made *ca*. 1230 probably in Damascus, the first complete (#104), the latter with replacement rete (#103) (see **XIVd-2**); on these the thrones and some of the inscriptions are inlaid in silver. Finally, one Mamluk Egyptian astrolabe with inscriptions in Arabic and Coptic (#4036) has all the inscriptions on the rete, the mater, the back and the plates inlaid in silver (see **Figs. 18** and **XIIIc-3.2**).[215] There are numerous examples of Mamluk metalwork which reflect the skill and enthusiasm of Egyptian and Syrian craftsmen in inlaying silver and gold in brass: one of the most magnificent is the basin known as the "Baptistère de Saint Louis" in the Musée du Louvre, from the second half of the 13th century.[216] If we were to suppose that Masʿūd was an

[212] An illustration of the front is in Culver, "Early European Instruments", p. 34. See also Gunther, *Astrolabes*, II, pp. 361-362 (no. 213); Gunther's dating to the end of the 16th century is much too late.
[213] Cartouches are common on later Islamic astrolabes from Safavid Iran (17th and early-18th century), particularly for arguments on scales and place-names in geographical gazetteers.
[213a] On this piece, only recently studied for the first time, see Mendoza Eguaras, "Astrolabio de Granada", and *Madrid MAN 1992 Exhibition Catalogue*, p. 227 (no. 44).
[214] An astrolabe with silver inlay is mentioned as belonging to a barber in one of the *1001 Nights*. Here the account is surely inspired by a Syro-Egyptian astrolabe (the entire corpus of tales is Syro-Egyptian in origin, although the location of the alleged events is Baghdad). The text is extremely corrupt yet can be partially restored to reveal the astrological implications of an observation that was reportedly made. For two studies of this text see Vernet, "La conjunción del barbero", and Maddison, "The Barber's Astrolabe".
[215] On this piece, see n. 251 below.
[216] See Mayer, *Islamic Metalworkers*, pp. 74-75, and, most recently, Behrens-Abouseif, "Baptistère de Saint Louis".

Egyptian or Syrian, then it could be possible either that he commissioned the silver cartouches and showed his predecessor how to inlay them, or that he actually collaborated with that person in preparing them for his own use. On the other hand, as we shall see, it seems more likely that the silver inlays derive from an Andalusī tradition, not least by virtue of their shape.

The question *why* anyone would want to highlight with silver inlay the names of the signs of the zodiac and the solar months is another matter. Perhaps we are witness to some interest in the astrological significance of the zodiacal signs, which is richly reflected in a subset of inlaid Islamic brassware.[217] This having been said, it should be noted that on the richly-decorated astrolabes of ʿAbd al-Karīm al-Miṣrī mentioned above, the names of the signs and months are not inlaid. Furthermore, only rarely do medieval European astrolabes bear astrological information on the scales on the back.[218] And alas #231, the only European astrolabe with artistic representations of the zodiacal signs in inlaid silver on the back is unavailable to us.

It is easier to understand, for example, why the curves for the times of Muslim prayer (and no other features) are inlaid in silver on the plates of #109, made by the Yemeni Sultan al-Ashraf in 690 H [= 1291] (see **XIVa**): the times of prayer are the most important times during the Islamic day. Likewise, the curves displaying the altitude of the *qibla* or local direction of Mecca at Herat and Samarqand (and no other features) are inlaid in silver on the plates of #3595, an astrolabe made in 830 H [= 1426/27] for the astronomer-prince Ulugh Beg (**XIVd-1**).[219] The Prince was wont to oscillate between these two main cities of his realm, and in whichever he was, he could use his astrolabe to determine the sacred direction.

26 The shape of the cartouches

The cartouches are essentially rectangular (albeit with the longer sides as circular arcs to fit within the boundaries of the scales) with simple half-quatrefoil decoration at each end:

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[217] See most recently *New York MMA 1997 Exhibition Catalogue*, and another example in *Paris IMA 1995 Exhibition Catalogue*, p. 457 (no. 370).

[218] See Glasemann, "Zwei mittelalterliche französische Astrolabien", pp. 221-222 and 230, dealing with the astrological properties of the lunar mansions. This article explains the markings on #549, an unsigned astrolabe of the Vienna school dated 1457—see *Nuremberg GNM 1992-93 Exhibition Catalogue*, II, p. 583.

[219] See also the text to n. 252 below.

[220] Some examples:

- ❖ A bronze jug made by Shīr ʿAlī ibn Muḥammad Dimashqī in 872 H [= 1467/68]—see Mayer, *Islamic Metalworkers*, p. 83 and pl. XIV.
- ❖ A steel sabre from Ottoman Turkey, datable *ca*. 1540—see Welch, *Muslim Calligraphy*, pp. 94-95 (no. 30).
- ❖ Two undated signed Eastern Islamic copper vessels—see Mayer, *Islamic Metalworkers*, pp. 47 and 80, pls. VII and XII.
- ❖ A jewelled silver *Qur'ān* cover from Kasimov in Central Russia dated 1002 H [= 1593/94]—see *Kuwait Hermitage 1990 Exhibition Catalogue*, pp. 35 and 128-129 (no. 109).
- ❖ Some late-16th-century Iranian bath-pails, hawking drums, torch-stands and pouring vessels—see Melikian-Chirvani, *Iranian Metalwork*, pp. 306-311, *Geneva MAH 1985 Exhibition Catalogue*, p. 287, and *Copenhagen DS Catalogue*, p. 351.
- ❖ A copper wine-bowl from early-17th-century Isfahan by an Armenian craftsman—see Welch, *Muslim Calligraphy*, pp. 142-143 (no. 57).

Cartouches of this kind are not uncommon on late Islamic metalwork from Syria eastwards,[220] as well as in *Qurʾān* illumination from 15th- and 16th-century Turkey and Iran,[221] but they are also found on various Naṣrid and *mudéjar* objects.[222] Indeed, essentially rectangular cartouches are a rather prominent feature of Naṣrid and *mudéjar* decorative art.[223]

The reader should be aware that we are dealing with an extremely simple design, when viewed in the light of the almost unlimited sophistication and variety of Andalusī decorative art.[224] However, one should be careful in assigning a particular design of this simplicity to any regional school. As a warning, one might cite the presence of cartouches precisely like those on this astrolabe, with a quatrefoil attached at the extremity, in the decoration of the Mosque of Ibn Ṭūlūn in Cairo, built during the period 876-79.[225]

As noted already in **2.5** and **2.16**, the sides of the cartouches coincide with the corresponding sections of the circles defining the solar and calendrical scales. The marks of hammering on the inside of the mater confirm that the cartouches did not cover any original inscriptions. And they correspond to medieval techniques of preparing the surface to enable the brass to better receive the molten silver.[226]

27 The decoration around the names of the zodiacal signs in the outer cartouches

Above the names of the zodiacal signs on the back various Arabic letters and vowel-signs have been inserted; some examples are shown in **Figs. 9a-b**. One might have expected some symbols denoting, say, the astrological lords of the various signs,[227] but the presence of these markings can

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- ❖ An "Elijah chair" (date uncertain) for circumcision ceremonies, in a synagogue in Qaṣr Shirīn in Iranian Kurdistan—see *Sepharad*, p. 76.

Most Iranian cartouches are pointed at the ends, as can be seen from a perusal of Melikian-Chirvani's splendid book, *Iranian Metalwork*. See also n. 118 above on a terracotta font from 14th- or 15th-century Muslim Spain with oblong cartouches, also with pointed extremities.

[221] For two examples see Lings, *Quranic Calligraphy and Illumination*, pls. 88 (15th century Turkey), and 90 (16th-century Iran).

[222] Notably, five pieces with cartouches of this kind, sometimes separated by quatrefoils:

- ❖ A silk pillow cover of Sancho IV, late 13th century—see *Granada-New York 1992 Exhibition Catalogue*, p. 112, fig. 8.
- ❖ Fragments of a silk textile from Naṣrid Granada—see *Ars Hispaniae*, IV, p. 199, fig. 214.
- ❖ A glazed and painted terracotta tile designed as a textile, from Granada, datable *ca*. 1410—see *Ars Hispaniae*, IV, p. 185, fig. 191, and more especially *Granada-New York 1992 Exhibition Catalogue*, pp. 360-361 (no. 113).
- ❖ Some *mudéjar* plaster decoration on the Alcázar in Seville, 1362—see *Ars Hispaniae*, IV, p. 371, figs. 426-427.
- ❖ Some *mudéjar* decoration on the interior walls of the Iglesia de Santa Justa y Rufina in Maluenda (Zaragoza)—see *ibid*., IV, p. 274, fig. 297.

See also the more developed red oblong cartouches on a silk textile fragment from the 14th century featured in *Granada-New York 1992 Exhibition Catalogue*, p. 335 (no. 97).

[223] A good example is the richly-decorated Naṣrid sword and scabbard in the Bibliothèque Nationale de France, datable to the late 15th century. See *ibid*., pp. 284-286 (no. 61), although the five oblong cartouches with ends shaped < and > are actually on the side other than the one illustrated there, and they are better seen in *Paris BN 1981 Exhibition Catalogue*, no. 6: "epée de Boabdil".

[224] See n. 137 above.

[225] Pavón Maldonado, *El arte hispanomusulman*, p. 114 and 117, design no. 90.

[226] On these see Ward, *Islamic Metalwork*, p. 35-37, with illustrations.

[227] See Hartner, "Astrolabe", B, pp. 2547-2548 (pp. 304-305 of the reprint).

partly be explained. We repeat the data, reminding the reader that Ø denotes a *sukūn* or zero-vowel sign, * denotes a *shadda*, the sign denoting a doubled consonant, and ʾ represents the weak guttural *hamza*. (The last may be a vaguely degenerate floral design, like a barbed fishhook.[228]) Furthermore the vowels *a*, *i* and *u* are written in the inscriptions as *ā* (= *alif*), *y* (= *yāʾ*), and *w* (= *wāw*).

al-ḥamal: *Ø—Ø—u* | *al-thawr*: *u—a or* Ø (squashed)
al-jawzā: Ø (altered) | *al-saraṭān*: no marks
al-asad: *Ø—z (= zāy)—d (= dāl)* | *al-sunbula*: *ʾ—a—i*
al-mīzān: *ḥ (= ḥāʾ)* or *j (= jīm)—Ø* | *al-ʿaqrab*: *Ø—Ø*
al-qaws: *Ø—a* | *al-jady*: *a*
al-dalw: *a—** | *al-ḥūt*: *ʾ—a*

Thus by *al-ḥ-m-l* for Aries we find what could be taken as one or two *sukūn*s (zero vowel signs, Ø) and a *ḥamma* (*u*-vowel). It is doubtful whether the engraver thought these would help the pronunciation. Correctly the word would be written in full *alØ-ḥamalu*, so that the word does have one *sukūn* and one *ḥamma* (this latter would normally be suppressed in pause, as in an inscription), but not where the engraver put them. This kind of interpretation is confirmed by the *alif* (for an *a*-vowel) and a *shadda* (for a doubled consonant) after *al-dalw* for Aquarius. Correctly, the word would be written *al-d*alw* in pause, pronounced *ad-dalw*, so that a *shadda* and an *a*-vowel are appropriate, again if not where he put them. Similar arguments could be made for the two *sukūn*s on *al-ʿaqrab* (from *alØ-ʿaqØrab*), the *sukūn* and the *a*-vowel on *al-qaws* (from *alØ-qawØs*), and the *a*-vowel on *al-jady*. But this explanation does not hold for all of the signs, and it seems that Masʿūd has simply used some of the various symbols as decoration. One implication of the above correspondences is that Masʿūd copied these from some heavily vowelled original (see below) and used the vowels somewhat indiscriminately. In addition, he also used criss-cross designs and simple flourishes to fill the remaining void spaces (see **3.29**).

The *d* (= *dāl*) above the final letter of *al-asad* is an acceptable Arabic usage.[229] But the *z* (= *zāy*) above the *s* (= *sīn*) in *al-asad* was perhaps intended to show that the word was to be pronounced *al-azad* or *al-açad*. (Note the problems that non-Arabs have with the single *sīn*, so that, for example, the Arabic Ḥasan becomes Hassan and the Syrian al-Asad becomes El-Assad.) Early European attempts to render *qalb al-asad*, "the heart of Leo", included: *Calbalazeda*, *Galbalaceda*, *Calbalaceda*, *Calbalaze*, *Calbalazed* and *Kalb eleced*;[230] some of these surely reflect Spanish usage. More difficult to account for is the *ḥ* (= *ḥāʾ*) or *j* (= *jīm*) above the *z* (= *zāy*) in *al-mīzān*. The letter has no dot so could be read as *ḥ*, but it is given in the initial form, which is usually used, with or without a dot, for *j* in the *abjad* notation.[231] The *j* seems more probable, but a linguistic explanation of its presence is not apparent.

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[228] Some examples are shown in *Granada-New York 1992 Exhibition Catalogue*, p. 337, on a late-14th-century Naṣrid pluvial.
[229] See n. 122 above.
[230] Kunitzsch, *Arabische Sternnamen*, p. 76 (no. 30).
[231] Irani, "Arabic Numeral Forms", pp. 5-6 (pp. 714-715 of the reprint).

An alternative possibility, namely, that we might find here some coded message or magic formula, seems unlikely.[232] All that we have in the way of letters are ʾ (*hamza*), *zāy*, *dāl* and *jīm*, and even when combined with any set of vowels, or interpreted as a set,[233] even with a mystical interpretation,[234] or read as numbers (1, 7, 4 and 3),[235] these do not seem to have any connection with codes or letter-magic or numerology.[236]

28 The names of the months and the decoration of the inner cartouches

In the month-names, vowels that could theoretically stand for *a*, *i* or *u* or even a zero vowel are represented by *v* in the following rendering:

yvnāyvr—fvbrā[y]vr (with one dot on the y instead of two)*—mārvs—*
vbrīl—māyū—yūnvyu (the *-h* ending indicates a short *-u* or *-uh)—*
yūlvyu (as for the previous month)*—vgh̲vsh̲t—sh̲vtvnbvr—*
vktūbvr—nūvnbvr—dvjvnbvr

These are most probably intended as:[237]

yanāyir—fabrāyir—mārs—abrīl—māyū—yūnyu—
yūlyu—agh̲ush̲t—sh̲utanbar—uktūbar—nuwanbar—dujanbar

The form *māyū* is unusual; usually in Andalusī sources, both texts and astrolabes, we find *māyu*(*h*).[238] It seems that Spanish (or Portuguese, but not Catalan) influence is to be seen here.[239]

There are various mainly redundant but nevertheless correctly-placed *sukūn*s on these names. Of particular interest are the various *shadda*s (*), namely, on the *s* (= *sīn*) of *mʾrs*, the *t* (= *tāʾ*) of *shtnbr*, the *k* (= *kāf*) of *ʾktūbr*, and the *w* of *nwnbr*. It was a custom in Spanish Arabic to represent various European letters by the closest Arabic letter with a *shadda* attached.[240] Thus, for example, *č* was written as *j**, *ñ* by *n**, and *p* by *b** or *f**. It may be that the *shadda*s used here were intended to denote that the month-names should be pronounced *mārss* (why is not at all clear), *shattanbar* (< *shaptanbar*? although *pt* → *t* is attested in Spanish Latin[241]), and *nuvambar*. The *shadda* in

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[232] On Arabic letter-magic and cryptography and see the articles "Ḥurūf, ʿIlm al-" and "Muʿammā" in EI_2. The standard work on Islamic magic is Fahd, *Divination arabe*, to which must now be added the splendid contribution of Emilie Savage-Smith to *London Khalili Collection Catalogue.*

[233] If one had a set of the seven letters *jīm*, *zāy*, *kāf*, *ṣād*, *qāf*, *thāʾ*, and *ghayn*, one might be dealing with the Maghribi variant of the letters corresponding to the element water (EI_2, III, p. 595b, also Schimmel, *Calligraphy and Islamic Culture*, pp. 92-93), and could come to the not unrealistic conclusion that Masʿūd intended to flee Spain by boat.

[234] Thus in 9th- and 10th-century Ismāʿīlī mysticism, *alif* stands for the Divine Order, *jīm* for the Soul, *dāl* for Nature, *zāy* for the Heavenly Spheres, *etc*.: see Schimmel, *Calligraphy and Islamic Culture*, p. 93.

[235] Ignoring the *hamza*(s), we note that the date 743 H, which corresponds to a year in the mid-14th century, close to the time when this astrolabe was made, would be written with the letters for 700, 40 and 3, not 7, 4 and 3.

[236] On the 14th-century Syrian box mentioned in n. 268 below there is an inscription which defied interpretation by its publisher but which simply reads *budūḥ*, a well-attested talisman on which see the article "Budūḥ" in EI_2, Supplement.

[237] The vowelling is not secure. See, for example, Corriente, *Dictionary of Andalusi Arabic*, p. 174, where for December we find *dujunbur*, *dujunbir*, *dujanbir*, and *dujunbar*, some, if not all of which, result from the "feel " of the editors of the sources used by Corriente.

[238] *Ibid*., p. 492, and Maier, "Romanische Monatsnamen", B, p. 256.

[239] Merlo, *Nomi romanzi dei mesi*, p. 129.

[240] Article "al-Andalus. x: Spanish Arabic" in EI_2, by G. S. Colin, especially p. 502a, and Colin, "Charte hispano-arabe", p. 377, n. 2.

[241] Castro, *Glosarios latino-españoles*, p. xliii.
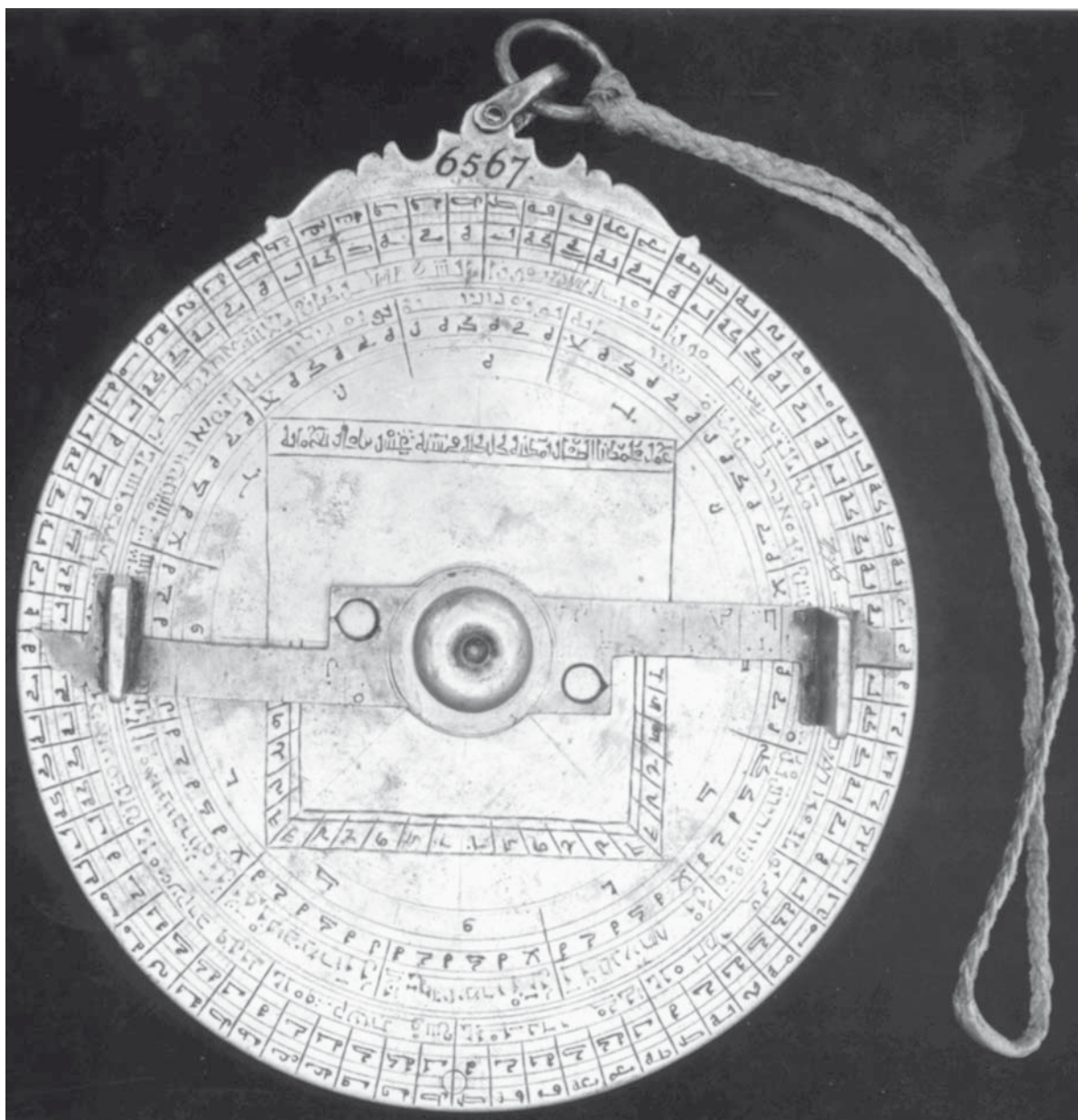
Fig. 15: The back of the astrolabe made in Cordova in 420 H [= 1029/30] by Muḥammad ibn al-Ṣaffār (#116). The Arabic engraving on the solar and calendar scales is complete with *sukūn*s and vowels, and the Hebrew names of the signs and the months have been added to the Arabic ones. [Photo courtesy of the Deutsche Staatsbibliothek, Berlin.]

ʾ*k***tūbr* makes less sense, unless—and this seems *most* unlikely—it is misplaced and it is supposed to denote that the initial *alif* be pronounced as a short *o*.

As with the decoration of the outer cartouches, it may be that the signs were inspired by similar markings on an earlier Andalusī astrolabe, such as one of the pieces of Muḥammad ibn al-Ṣaffār. Now it so happens that two astrolabes made in Toledo by the same maker, Muḥammad ibn al-Ṣaffār, the first #3650, dated 417 H [= 1026/27] and the second #116 made three years later,[242] present some of the very features that might have inspired Masʿūd. The engraving on these pieces is distinctive and loaded with mainly redundant *sukūn*s and occasional vowels—see **Fig. 15**.[243] At least the first of these pieces was probably still in Toledo in the 14th century, as attested by the Hebrew name for Toledo on the appropriate plate (and also Cordova on another). One has perhaps to imagine another piece by the same maker, in the same distinctive and perverse Andalusī Kufic, extremely difficult to read,[244] on which there were also a few vowel signs as well.

29 The endless knots on the cartouches

The criss-cross patterns like frames for a "noughts and crosses" game on the silver cartouches, and also near the end of the inscription on the shackle, are incomplete renderings of endless knots.[245] Three complete forms are found in the cartouches for *al-ḥamal* (Aries) and *al-jady*

Fig. 16: Endless knots on a 13th-century silk fragment from the Kingdom of Granada. Note also the use of ornamental *naskhī* script and the superfluous *sukūn*s at the beginning and end of the inscription *al-baraka li-ʾllāh*, "Blessing is from God". [Courtesy of the Instituto de Valencia de Don Juan, Madrid, inv. no. 2093.]

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[242] See n. 22 above. Mayer, *Islamic Astrolabists*, pl. II, shows the back, unencumbered by an alidade.

[243] See already Maier, "Romanische Monatsnamen", B, p. 60, where it is noted that the *sukūn*s are "teilweise redundant verwendet", that is, "partly used redundantly".

[244] Thus Woepcke misread the name of the maker as "ibn al-Saal" (that is, ibn al-Ṣāl), an error repeated in Goldstein & Saliba, "Hispano-Arabic-Hebrew Astrolabe", p. 19, n. 2. On #116 the name certainly looks like al-Ṣāl, but the medial *f* (= *fāʾ*) has been engraved like a *sukūn* above the horizontal line between the *ṣ* (= *ṣād*) and the long *a* (= *alif*). On #3650 the name al-Ṣaffār is clear. See also King, "Three Sundials from al-Andalus", p. 360, n. 10, on the problems of reading the name al-Ṣaffār in Andalusī Kufic on a marble sundial from *ca*. 1000.

[245] The term "endless" is to be somewhat loosely interpreted, and I use it to include interwoven endless loops or superposed folded strands. The only transcultural account I have found is, inevitably, Baltru·aitis, *Le Moyen Âge fantastique*, pp. 92-95.
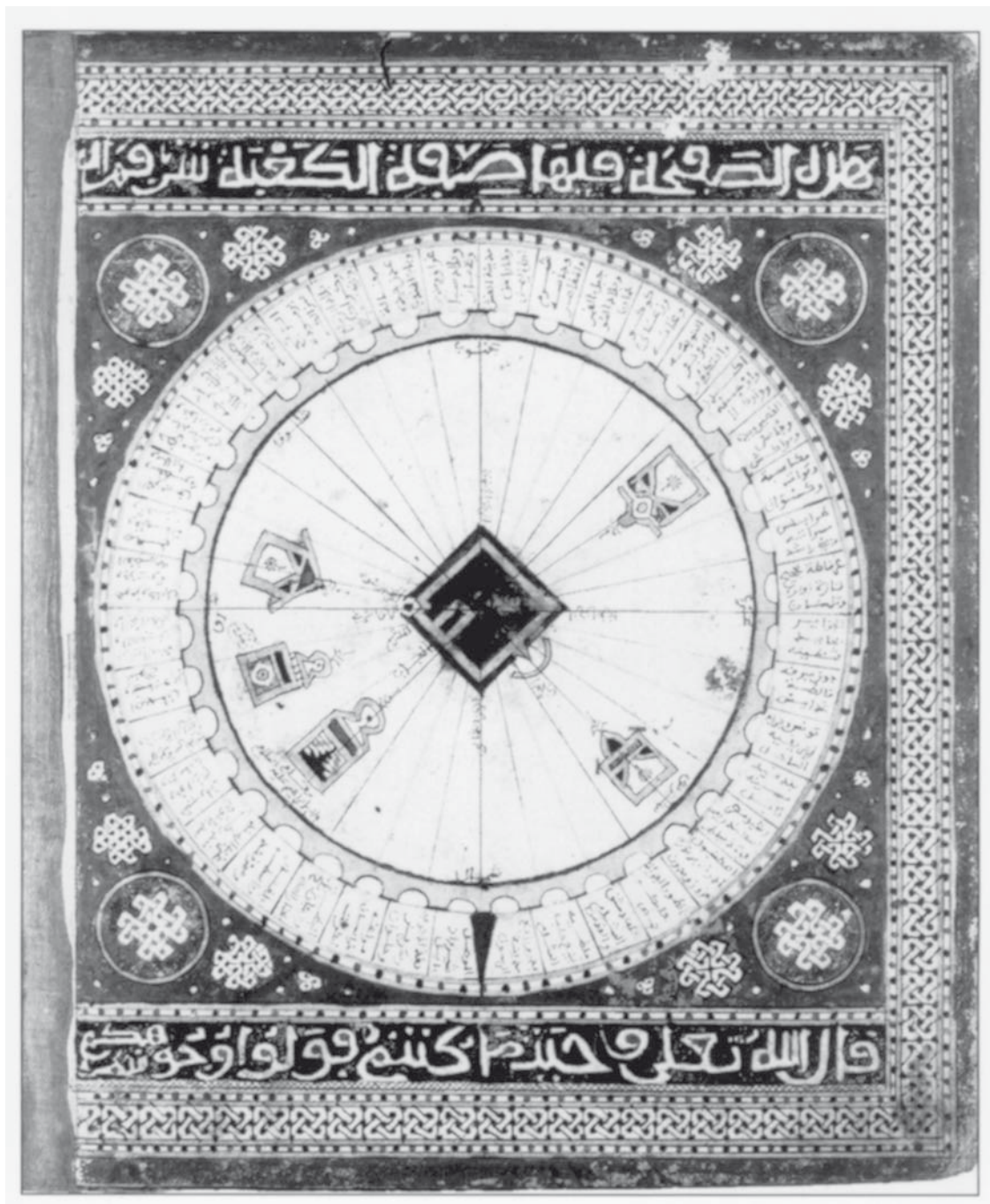
Fig. 17: Decoration with endless knots on a diagram of sacred geography in the 16th-century Tunisian nautical atlas of ʿAlī al-Sharafī al-Ṣafāqusī. [From MS Paris BNF ar. 2278, courtesy of the Bibliothèque nationale de France.]

a

b

Figs. 18a-b: A knot as decoration on the rete of an astrolabe with Arabic inscriptions but numbers in Coptic (#4036) made in Cairo in 681 H [= 1282/83]. The knot is not independent; rather, it forms part of a larger pattern. [Courtesy of the Turkish and Islamic Archaeological Museum, Istanbul.]

Fig. 19: A decorative knot on the rete of an astrolabe by Maḥmūd ibn Jalāl (al-Kirmānī) dated 833 H [= 1429/30] (#4320). [Courtesy of Sotheby's, London.]

(Capricorn), and *dujanbar* (December)—see **Figs. 9a-b**. These endless knots, admittedly here sometimes fudged at the ends, were used as incidental decoration in Islamic art,[246] especially in Hispano-Mauresque art, most notably in Aragon.[247] They are also apparently known from Islamic magic.[248] We find similar but more complex knots, for example, on a 13th-century silk fragment from Granada (**Fig. 16**),[249] and in an illustration of Islamic sacred geography—the world divided into sectors centred on the Kaʿba—in a 16th-century Tunisian navigational atlas (**Fig. 17**).[250] As decoration on an astrolabe, only three examples of knots come to mind, namely:

(1) on the rete of an astrolabe with Arabic inscriptions but numbers in Coptic (#4036) made by Ḥasan ibn ʿUmar al-Naqqāsh in Cairo in 681 H [= 1282/83] (see **Figs. 18a-b** and **XIIIc-3.2**);[251]

(2) on the rete of the astrolabe (#3595) made for Ulugh Beg by Jalāl al-Kirmānī, the astrolabist at the Samarqand observatory, in 830 H [= 1426/27] (see **Figs. XIVd-1.1** and **1.3a**);[252] and

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[246] Such designs are known from Iranian, and also Syrian and Egyptian, decorative art. Some examples:
- ❖ an inkwell in brass with silver inlay, 12th century—*Kuwait 1990 Hermitage Exhibition Catalogue*, pp. 54-55 (no. 29);
- ❖ a bronze vase inlaid with silver, 12th- or early-13th-century Khurasan—Welch, *Muslim Calligraphy*, pp. 110-111 (no. 39);
- ❖ four mortars, Khurasan, between late 12th and 14th century—*London NG Catalogue*, II, pp. 312-313 (nos. 194-196) and 316-317 (nos. 199-201).

For endless knots in the decoration of a Hebrew manuscript from Toledo, *ca*. 1300, see Sed-Rajna, "Ateliers de manuscrits hébreux", fig. 3 on p. 348. For examples of endless knots tied into Arabic and Hebrew script see, for example, Lanci, *Simboliche arabiche*, III, pls. XXIX, XLIII, LVII, LIX and LI (Arabic, the last with the name of Allāh developed into a knot) and XLIV (Hebrew).

[247] In addition to the two Western Islamic sources mentioned below (nn. 249-250), see other examples in Pavón Maldonado, *El arte hispanomusulman*, pp. 62-63 and 96 (general), and pp. 94, 100, 102, 106, 107, 109 and 384. In particular we note:
- ❖ a design similar to the ones on the astrolabe in the Claustro de San Juan de Castrojeriz near Burgos (*ibid*., p. 94);

and various "endless" knots from *mudéjar* architecture in Aragon, namely:
- ❖ one from the Aljafería in Saragossa (*ibid*., fig. 104, no. 18);
- ❖ two from the Catheral of Teruel (*ibid*., pl. 12 opposite p. 384).

More complicated patterns are to be found, for example, in:
- ❖ two 12th-century Almoravid *Qurʾān*s dated—*Granada-New York 1992 Exhibition Catalogue*, pp. 304-306 (nos. 75-76);
- ❖ a brass basin inlaid with gold and silver, dated 1252/53, Syria (?)—*Washington FGA 1986 Exhibition Catalogue*, p. 19, fig. 9; and
- ❖ a brass pierced globe inlaid with silver and black, Syria or Egypt, mid 14th century—*ibid*., pp. 171-172 (no. 23).

Yet more complicated patterns of all are to be found on European work inspired by Hispano-Mauresque art, for example:
- ❖ a majolica plate made in Siena *ca*. 1525—*Berlin MGB 1989 Exhibition Catalogue*, pp. 613-614 (no. 4/121); and
- ❖ a bronze plate with inlaid silver made in Venice *ca*. 1545—see *ibid*., pp. 203 and 603-604 (no. 4/100).

[248] Yet they are not mentioned, for example, in Kriss & Kriss-Heinrich, *Volksglaube im Islam*.

[249] See *Granada-New York 1992 Exhibition Catalogue*, p. 111, fig. 7 (also n. 272 below).

[250] On Islamic sacred geography see my EI_2 article "Makka. iv. As centre of the world" (repr. in King, *Studies*, C-X), especially fig. 7, also **VIIa-2**. On the navigational atlas of Aḥmad al-Sharafī al-Ṣafāqusī see Nallino, "Mappamondo di ash-Sharafī", and a study, now well advanced, by Mónica Herrera Casais (Frankfurt and La Laguna).

[251] #4036: Istanbul, Turkish and Islamic Archaeological Museum, inv. no. 2970—unpublished, though see **XIIIc-8.2**. See also the text to n. 215 above.

[252] See the text to n. 219 above. For illustrations of the rete see already *Copenhagen DS Catalogue*, p. 214, and

(3) on the rete of the newly-rediscovered astrolabe (#4307) by Jalāl's son, Maḥmūd, dated 833 H [= 1429/30] (see **Fig. 19**).[253]

The inspiration for the Andalusī tradition was most probably the highly elaborate knots in 10th- and 11th-century Visigothic manuscript illumination.[254]

30 The Spanish Arabic inscriptions reviewed

Masʿūd has left us a unique document attesting to his vernacular Arabic. The star-names *dabrān* < *dabarān*, *ghumayṣa* < *ghumayṣāʾ* and *ṭāyir* < *ṭāʾir*; the month-name *māyū*; and the place-name *al-Jazāyir*. Possibly the *sukūn* on the *ṣ* (= *ṣād*) in *ṣāḥibuhu* at the beginning of his inscription on the boss of the shackle is intended to be on the *ḥ* (= *ḥāʾ*), so the word would be pronounced *ṣāḥbuh(u)*. The *shadda*s (*) on various Arabic letters in the month-names appear to be purely decorative.

31 One of the earliest surviving screws?

The only other known medieval astrolabe with a screw attachment is the 14th-century Picard piece #202.[255] In both cases, the screws are hand-worked and appear to be original. If this is the case, then we are dealing with some of the earliest European examples of screws.[256] But it is easier to account for the male screw than for the thread inside the female cylindrical bolt. Here again metal analysis might be useful to investigate further whether these paraphernalia are original.

4 Concluding remarks

1 Who was the Jew who scratched the latitudes on the plates?

It may be that he was an assistant to the person who made the Latin engravings, a skilled craftsman, but nothing more. We cannot know to what extent he was involved in the construction, most of which, for lack of evidence to the contrary, we attribute to the person who made the Latin engravings. We cannot exclude the possiblity that the "European" mentioned below was not identical with the Jew who scratched the latitudes on the plates, perhaps even a converted Jew, which would mean that a single individual engraved both the Hebrew numbers and the "Latin" inscriptions. In any case, the Jew appears to have been active prior to the pogroms and mass conversions in 1391, which heralded the collapse of the Jewish community in Spain.[257] The association of this Jew with

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King, "Strumentazione", pp. 161. The knot is independent, although attached to other decorative components of the rete.

[253] See *Sotheby's London 16.12.2003 Catalogue*, pp. 40-41 (lot 56).

[254] See, for example, *Madrid BN MSS Catalogue*, pl. VIII opposite p. 204, and *Madrid RAH MSS Catalogue*, pp. 91, 119 and 175.

[255] King, *The Ciphers of the Monks*, p. 419 and Fig. L.9.

[256] Two general histories of the screw are Treue, *Kulturgeschichte der Schraube*, and *Würth & Konstanz 1995 Exhibition Catalogue*. The screw was known in Antiquity, and on the development of the screw in Europe there is the chapter by A. P. Usher entitled "The screw and its development", in Singer *et al*., eds., *History of Technology*, III, pp. 334-339.

[257] Scheindlin, "Jews in Muslim Spain", pp. 198-199.

Toledo is strengthened by the fact that this was the major centre of metal-working in Spain in which Jewish craftsmen were involved.[258]

2 Who was the person behind the Latin engraving?

He was a local artisan, local to either Toledo or Saragossa, and was probably a Christian. He was a competent astrolabe-maker and engraver, and he adhered to a local tradition of using the old-fashioned inverted forms of '2' and inverted bar fractions. He favoured a distinctive scholastic orthography for the Latin script: the '**9**' for a hard C. Can this have been his own convention? Certainly, we do not find it elsewhere. Yet, he was not that well-versed in Latin or the manuscript tradition of star-names that he did not make mincemeat of some of the star-names on the rete.

On the other hand, he may have been a Jew or a Jew converted to Chistianity, in which case he was probably identical with the Jew who scratched the latitudes on the plates (see above). His ancestors would have witnessed the Muslim domination come and go.

Whoever he was, he was very familiar with the design of Andalusī astrolabes, and copied outright an Andalusī design for his rete and an Andalusī design for his throne. But he was also influenced by the new tendency amongst European astrolabe-makers to include plates for latitudes in Northern Spain and in France up to as far north as Paris, and just beyond to Reims.[259] He favoured a mid-13th-century Toledan tradition of astrolabe stars, although it is a complete mystery how he could have produced a set of star-names that were so different from those used in that tradition. Also, he used a curious, inexact (and previously-undocumented) Andalusī procedure for marking azimuth curves on astrolabe plates.

3 Why was the astrolabe not completed as planned?

For some reason, the astrolabe was not completed by the one or two persons mentioned above. All that remained to be done was to engrave the names of the zodiacal signs and the months on the scales of the back, which had already been inlaid with silver cartouches. The rete and four original plates had been completed, and the arguments had been engraved on all of the scales on the back, as well as the labels on the shadow-squares. Then something happened.

One possibility is that the maker(s) died. A prime cause of premature death in the mid-14th century was the Black Death.[260] The plague hit Saragossa in the year 1348 and four-fifths of the Jewish population were wiped out.[261] But no end of other hypotheses could be formulated.

[258] See n. 9 above.

[259] We can distinguish various earlier tendencies amongst European instrument-makers: first, the tradition of marking plates for the climates of Antiquity (as on #161 and #166, with relics on #169 (2nd climate only); see also #4024, a 10th-century Andalusī astrolabe with plates for the climates); second, the tradition of #3042, also left over from Antiquity (see n. 176); and third, the tradition of marking plates for a series of latitudes and an over-enthusiastic association of these with localities such as Africa and Macedonia (see again n. 176 on #416). See further **XVI**.

[260] See n. 11 above.

[261] Article "Saragossa" in *EJ*, especially col. 861.

4 Who was Masʿūd?

Masʿūd is a Muslim Arab name. (It is also a Christian Arab name, but it has no Hebrew equivalent.) Neither instrument-maker nor metal-worker with this name is known in the secondary literature.[262] Masʿūd was a competent astrolabist in touch with the medieval Islamic astronomical-geographical tradition, because the fourth plate is executed with reasonable care for the correct latitudes. He was also a skilled engraver, as is apparent from his inscription on the boss of the shackle. He was needy (*faqīr*) in the standard Islamic sense, namely, needy of the mercy of God, and the use of this term indicates that he engraved the inscription himself. The epithet *al-wāthiq*, "he who trusts", is usually applied to rulers,[263] but even they, in Islamic civilisation, trusted in God, here called *al-malik al-maʿbūd* in order to rhyme with Masʿūd.[264] The term *al-malik* is one of the names of God,[265] but the expression *al-malik al-maʿbūd*, "the King who is to be worshipped", is neither *Qurʾān*ic nor is it attested in the statements attributed to the Prophet Muḥammad; indeed, it is not happily Islamic. Nor is it Biblical, although the choice of words is vaguely reminiscent of the *Psalms*.[266] The word *maʿbūd* is, however, used to refer to God by the famous poet and religious philosopher Jūdah Ha-Lēvī (b. Tudela, *ca*. 1075, *fl*. Granada then Toledo, d. Cairo, 1141) in his discussion of the First Commandment: he renders Hebrew *elohekha*, "your God", by *maʿbūduka*, "the object of your worship".[267] In passing we note the existence of an unpretentious 14th-century Mamluk brass box with silver inlay in the Metropolitan Museum of Art in New York[268] which bears an inscription apparently identifiying the maker and the person who commissioned the piece: the latter is named *al-Wāthiq bi-ʾl-malik al-walī* ibn Muḥammad. Here again the expression

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[262] This is essentially limited to Mayer, *Islamic Astrolabists*, and *idem*, *Islamic Metalworkers*.

The Masʿūd al-Dahhān who translated a history of the Jews by Judah ben Moses Mosconi ("pseudo-Josephus") of Ohrid in Serbian Macedonia from Hebrew into Arabic at an unspecified date (published in Livorno in 1886), is hardly a candidate, although Mosconi did travel to the Maghrib and to Perpignan *ca*. 1360—see Sarton, *IHS*, III:2, p. 1451. Another non-candidate is Abū or Ibn Masʿūd of Seville, head of Maghribi *madrasa*, who commissioned a book on magic, apparently at the end of the 14th century—*ibid*., III:2, p. 1521.

[263] Indeed, the Ḥafṣid ruler of Tunisia in the middle of the second half of the 13th century was called Abū Zakariyāʾ King, Yaḥyā al-Wāthiq—see de Zambaur, *Manuel*, p. 74; Bosworth, *Islamic Dynasties*, new edn., pp. 45-46; and the article "Ḥafṣid" in EI_2, especially p. 67a. See also Brockelmann, *GAL*, SII, p. 232, for a mid-14th-century Zaydī Imām of the Yemen named *al-Wāthiq bi-llāh* al-Muṭahhar. The same title was held by an Abbasid and an Almohad ruler.

[264] Yet the two lines do not display a poetic metre in the traditional sense of Arabic poetry (see the EI_2 article "ʿArūḍ").

[265] Articles "Malik" [= king] and "al-Asmāʾ al-ḥusnā" [= the 99 names of God], (no. 4), in EI_2.

[266] As a curiosity we note that the terminology is even more reminiscent of the Protestant hymn beginning:

"O **Worship** the **King**, all glorious above,"

and with a line in the fifth verse:

"In Thee do we **trust**, nor find Thee to fail."

These words were composed in 1833 by Robert Grant, and are supposedly based on Psalm 104.

[267] I owe this information to the kindness of Tzvi Langermann. See his "Science and the *Kuzari*", p. 500, n. 5.

[268] Atıl, *Mamluk Art*, p. 104, no. 36 (The Edward C. Moore Collection, inv. no. 91.1.538). The inscription supposedly reads: *mimmā ʿamila[hu] bi-rasm al-wāthiq bi-ʾl-malik al-walī ibn Muḥammad Muḥammad ibn ʿAlī al-Ḥamawī al-muwaqqit bi-ʾl-jāmiʿ al-umawī*, which, if it is correct, could be taken as meaning "This was made by Muḥammad ibn ʿAlī al-Ḥamawī, the professional timekeeper at the Umayyad Mosque (in Damascus), by order of *al-Wāthiq bi-ʾl-malik al-walī* ibn Muḥammad". The work is of the "provincial type of metalwork available to the middle classes" (Atıl). The maker is not listed in Mayer, *Islamic Metalworkers*, and is unknown to the history of Islamic astronomy. The client has not been identified.

al-malik al-walī, "the king who is the protector", that is, God, is not *Qurʾān*ic, although *al-walī* this time *is* one of the 99 names of God.[269]

There is a flavour of dissimulation in Masʿūd's inscription of ownership, as if he did not want to mention the name of God. Neither, as we have noted, did he engrave the name of Mecca on the plate for the latitude of the holiest city in Islam; nor did he label the special markings for the times of Muslim prayer on the plates for Algiers, Mecca and Jerusalem. Whilst any *mudéjar* in the 14th or 15th century would try to be careful with what he wrote, we may have here, in what he did not write, a vague hint that he was a prisoner of the Christians.[270]

No individual named Masʿūd from al-Andalus with an interest in astronomy is known. But there is one man Masʿūd who was the father of an astronomer, and the family had both an Andalusī and a Maghribi connection.[271] Also, the date of the father would correspond to a dating of the astrolabe to the mid 14th century. The family appears to have been Andalusī in origin. The son, possibly born in Tlemcen, some 500 km WSW of Algiers, was *imām* and *muwaqqit* in Fez, Tunis, Jerusalem and Damascus, and in the last-mentioned city he became a chief judge of the Mālikī legal school. Andalusī and Maghribi emigrants to Syria would have been adherents of the Mālikī school, which was predominant in al-Andalus but barely represented in Syria. It is a far cry from

[269] See the article "al-Asmāʾ al-ḥusnā" in EI_2 (cited in n. 265), (no. 56).

[270] The veiled inscriptions of Muslim prisoners and slaves under Christian domination were in general less subtle—see van Koningsveld, "Muslim Captives".

[271] A certain ʿIzz al-Dīn ʿAbd al-ʿAzīz ibn Saʿd al-Dīn Masʿūd ibn ʿIzz al-Dīn ʿAbd al-ʿAzīz al-Tilimsānī al-Mālikī was *imām* and *muwaqqit* in the cities of Fez, Tunis, Jerusalem and Damascus. (The epithet al-Tilimsānī indicates that he hailed from Tlemcen.) He oversaw the copying of MS Escorial ar. 932 of the astronomical handbook of Ibn Abi ʾl-Shukr al-Maghribi (compiled in Damascus in 1258) in Tunis in the year 797 H [= 1394/95], and his name and these affiliations are given in this form in a colophon (fol. 57v). See Samsó, "Maghribi *Zīj*es", p. 96; this information is overlooked in the description of the manuscript in *Escorial Catalogue B*, pp. 43-44.

Also, Ibn Masʿūd was the author of a treatise on the quadrant with trigonometric grid (see the article "Rubʿ" in EI_2) compiled in Cairo in the year 795 H [= 1392/93] (on the context see King, "The Astronomy of the Mamluks"). This is known from a unique copy, MS Escorial ar. 918/14—see *Escorial Catalogue A*, p. 353; *Escorial Catalogue B*, p. 24 (also pp. 17 and 23); *Cairo ENL Survey*, p. 66 (no. C46); and Matvievskaya & Rosenfeld, *MAMS*, II, p. 324, no. 271a. The manuscript was copied in Maghribi script in the year 888 H [= 1483/84]. The same ʿAbd al-ʿAzīz is mentioned in a later Tunisian treatise on astronomical instrumentation (*Cairo ENL Survey*, p. 141, no. F39, on Abū Jaʿfar al-Tūzarī, *fl*. Tunis *ca*. 1450), and there is a quadrant made by him in 774 H [= 1372/73] preserved in the National Museum, Damascus.

Now the remarks in MS Escorial ar. 918 mention that ʿAbd al-ʿAzīz was the chief Mālikite judge (*aqḍa ʾl-quḍāt*) in Damascus. The Mālikī legal school was not strong in Syria (see "al-Mālikiyya" in EI_2), and it is somewhat surprising that there was a Mālikī official there with this prestigious title. But it was the major school in al-Andalus, and numerous Andalusī scholars emigrated to Syria at the time of the *Reconquista*. And in this manuscript ʿAbd al-ʿAzīz is referred to by an Andalusī name, Ibn *F-r-m-j-h* or *F-r-m-y-j-h* (vowelling uncertain), possibly derived from the Spanish *bermejo*, meaning "of a bright reddish colour". The first catalogue-entries for this Escorial manuscript provided the modern literature with an "Abdelaziz Massudus Hispalensis" (*Escorial Catalogue A*, p. 353), from whom developed an "Abdelaziz Abenmasud el Ixbilí (from Seville)" (Sánchez Pérez, *Biografías*, p. 34, also Vera, *MME*, p. 141); and an "ʿAbd al-ʿAzīz b. Masʿūd al-Ishbīlī (XIIe s.)" (Lamrabet, *Mathématiques maghrébines*, p. 38, no. 203), sometimes, as now in Matvievskaya & Rosenfeld, *MAMS*, with the additional fiction that he died in 1132 A.D.

Most of the above information is found in a recent doctoral thesis by M. Aguiar Aguilar, in which the author and his treatise on the sine quadrant are investigated for the first time (Aguiar Aguilar, "Tratado árabe oriental", pp. 97-98, *eadem*, "En torno a ʿAbd al-ʿAzīz b. Masʿūd", and *eadem*, *Tratado de Ibn Masʿūd*, pp. 461-468). There is more to be said, but neither this Masʿūd nor his son have been found yet in the available biographical works (including some mentioned, for example, in Fagnan, "Tabakāt malekites").

an astrolabe-maker in al-Andalus to a judge in Damascus, but in trying to identify Masʿūd we are indeed grasping at straws.

Masʿūd's engraving of the names of the signs and of the month-names and their decoration remains somewhat problematic. In fact, it is not very professional within the framework of the high standards of Islamic astrolabe engraving. Rather his work shows a certain amount of calligraphic licence and is more typical of inscriptions one might find, say, woven on textiles.[272] But his contribution is of extreme historical interest, for we are dealing with the only example of the influence of a local dialect on Arabic inscriptions on an astronomical instrument. And in his decoration of the cartouches Masʿūd was perhaps over enthusiastic. No criticism is intended here: in the workshops of the instrument-makers of the Middle Ages we do not expect the rigorous, and in many respects tedious, discipline of the madrasas and the monastic scriptoria. People simply did the best they could under the circumstances. We may also compare European instrument-makers who left off the names of stars on astrolabe retes because they could not understand the Arabic originals (#3042, #161 and #167)[273] or who confused the latitudes on the plates (#3915 and #4523),[274] or who left out both the star-names and the latitudes (#169).[275] An example of the very kind of Andalusī astrolabe which might have inspired Masʿūd is preserved for us, namely, #116, made in Toledo in 420 H [= 1029/30] by Muḥammad ibn al-Ṣaffār. It even bears additional markings in Hebrew script that appear to have been added in Toledo.

5 The Algiers connection

Algiers was founded in the 10th century on the ruins of the Roman city of Icosium.[276] A significant mosque was built there in the 13th century. A traveller of that century, al-ʿAbdarī, mentioned the exceptionally beautiful natural setting of Algiers and the imposing solidity of its ramparts, but added that there were no scholars there, indeed that his search for a single one was like looking for a horse full of camels' eggs.[277] He was comparing Algiers with Tlemcen, Bougie, Bône and Tunis, which did have an intellectual life, and indeed even a scientific life.[278]

Although it appears that Masʿūd made this engraving in Christian Spain rather than in Algiers, that city was clearly close to his heart. Now how could he have known that the latitude was around

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[272] Compare, for example, the text *al-baraka laka mina llāh*, "The blessings that you have are from God", on the 13th-century silk textile fragment in the Instituto de Valencia de Don Juan, Madrid, illustrated in *Granada-New York 1992 Exhibition Catalogue*, p. 111, fig. 7 (see already n. 249 above). Here the text is written on the left-hand side of a series of semicircular arcs open at the bottom with the *sukūn* of *alØ-baraka* on the line before the *al-*, and there is a redundant *sukūn* above or, rather, following the word *Allāh*. The inscription is repeated in mirror-image on the right.

[273] On the first see Kunitzsch & Dekker, "The Stars on the Carolingian Astrolabe". On the second, whose present location is unknown, only the description in Gunther, *Astrolabes*, II, p. 306 (no. 161), is available. No illustrations of the third have been published.

[274] On #3915 see nn. 26 and 176 above, and on #4523 see n. 177.

[275] On #169 see **XIIId-2.4-5** and **2.8**.

[276] See the article "al-Djazāʾir" [= Algiers] in EI_2.

[277] Cherbonneau, "Voyage d'El-Abdéry", A, pp. 157-158 (pp. 14-15 of the reprint), and B, pp. 54-55 (pp. 38-39 of the reprint).

[278] On the history of astronomy and mathematics in the Maghrib see King, "Astronomy in the Maghrib", and Djebbar, *Études*, respectively. Parts of the former are now superseded by Samsó, "Maghribī *Zīj*es", and *idem*, "Astronomical Observations in the Maghrib".

36°? In fact the latitude (correctly 36°50′) is given as 35;30° in the geographical tables of Ibn al-Zayyāt (al-Andalus, d. 1058) and al-Marrākushī (of Moroccan origin, *fl*. Cairo *ca*. 1280).[279] It may be that 35;30° was indeed the very latitude used by Masʿūd for his plate. Likewise, he probably used 21;40° for the latitude of Mecca, the value that was most popular amongst Andalusī astrolabe-makers.[280]

The astronomical markings on this plate serve not only Algiers, but also the middle of the fourth climate of Antiquity.[281] Plates for 36° with this in mind were common on Islamic and some European astrolabes.[282] Western Islamic astrolabes tended to have numerous place-names associated with the latitude on each plate, 35;20° usually being linked with Ceuta (Sabta) and 36° with Almería. But although some even from before *ca*. 1100 do feature Kairouan, Tunis, Tangiers and Ceuta, none bears markings for Algiers. In fact, only one piece from before *ca*. 1600 (#4046) has markings for Algiers, albeit with the absurd latitude 33;20°.

But what was Masʿūd's association with Algiers? One possibility is that he, a Muslim, planned to flee Christian-dominated Northern Spain for Algiers. A *hijra* or "breaking of ties" was advocated for all Muslims living under Christian domination.[283] The medieval population of Algiers consisted in part of refugees who had fled from the Christian reconquest of al-Andalus, and many of them established themselves as corsairs in Algiers. The first Jewish refugees from Spain arrived in Algiers in 1391.[284] In 1510 the Spaniards imposed a levy on the city and occupied the neighbouring islands, in order to suppress the corsairs.[285] This was taken by the Ottoman Turks as an invitation to liberate Algiers from both the Spaniards and the locals.

6 The origin of the astrolabe

Any attempt to understand how the instrument came to acquire its present form can only be partially successful.[286] The following reconstruction is at best hypothetical.

The instrument was begun in some centre of Christian Spanish culture in the 14th century; Toledo seems the most likely choice, although Saragossa is also a possibility. A Christian and a Jew collaborated on the construction, the only definitive traceable input of the latter being the latitudes scratched in Hebrew on the plates. It is also possible that there was only one individual

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[279] Kennedy & Kennedy, *Islamic Geographical Coordinates*, p. 19. On the two sources see *ibid*., pp. xxv (*sub* MAR) and xxxvii (*sub* ZAY).

[280] This value was sometimes approximated to 22° or 21;30°. See King, "Geography of Astrolabes", App. 1c, now in **XVI**.

[281] See n. 36 above.

[282] Thus, for example, on #2572 all of the plates serve specific localities, but that for 36° is marked for Almería and the 4th climate.

[283] Article "Mudéjar" in EI_2, cols. 288a-b. See also Buzineb, "Respuestas", on two *fatwā*s or religio-legal pronouncements dated 1392 and 1504 by Maghribi jurisprudents to this effect.

[284] Article "Algiers" in *EJ*.

[285] Article "Al-Djazāʾir" [= Algiers] in EI_2, p. 520a.

[286] A. J. Turner and E. Savage-Smith (in Turner, "Astrolabe exceptionel" / "Exceptional Astrolabe") suggested, largely on the basis of the Syrian-type throne, the Syrian-type silver cartouches, the plate for [36°], which would serve Aleppo, and the Andalusī-type rete, that the instrument must have been made in Egypt or Syria or even further east in Iraq or Iran by an Andalusī or Maghribi instrument-maker, but not completed, and that the "Latin" inscriptions were added later in Europe. To counter this one only need point out that that the throne is an attested earlier Andalusī design, that the silver cartouches are quite different from the silver inlay on known Syrian (and Egyptian) astrolabes, and that the markings for 36° and $21^1/_2$° are not by the same maker as the mater, rete and three other plates.

involved, perhaps a Christianized Jew. An unusual Andalusī-type design was chosen for the throne and for the rete, and an Andalusī, perhaps especially an Andalusī Jewish technique of silver inlay. With the inscriptions on the back not completed, the instrument changed hands. A Spanish Arab, a *mudéjar*, named Masʿūd, with an especial interest in Algiers, added the main Arabic inscriptions, providing the names of the zodiacal signs and the months with orthographical symbols perhaps inspired by an earlier Andalusī astrolabe. His engraving shows distinct Spanish Arabic influence. In addition, he substituted one of the plates for a new one serving Algiers and Mecca and engraved the inscription on the boss of the shackle identifying himself as the owner. He appears to have deliberately omitted the name of God in this inscription, the name of Mecca on his new plate, and any identification of the purpose behind the special curves for the times of Muslim prayer on his plate for Algiers and Mecca and and on the original plate for Jerusalem. Perhaps he intended to take the instrument to Algiers, and maybe someone there added the second layer of Arabic star-names. But it may be the astrolabe was never taken to Algiers, for a couple of hundred years later it was in Northern or Eastern France, where in the 16th century someone added the numbers on the outer rim.

The hypothesis that the astrolabe was made but not completed by a European and that it *later* fell into the hands of an Arab, namely Masʿūd, who added the first layer of Arabic star-names as well as the plate for Algiers and Mecca, would mean that the instrument in its uncompleted form was in circulation. Other questions have to be addressed but cannot be answered. If Masʿūd was a Christian or a Christian convert from Islam, then why did he engrave a plate for the latitude of Mecca? If Masʿūd was a Muslim, then why did he use the unusual expression *al-malik al-maʿbūd* to rhyme with his name? And a particularly vexing question is: why did Masʿūd engrave a plate specifically for Algiers?

Various other explanations are conceivable but not particularly convincing given the lack of concrete evidence. Perhaps the astrolabe, not yet completed, was taken in the 16th century by a Spaniard to sea and the pair captured by corsairs from Algiers. The Arabic additions might then have been made in Algiers itself. This would at least explain why the Arabic script looks later than the 14th century and how there came to be additional markings for Algiers (but no additional Arabic inscription for, say, Toledo). But one would hardly expect a corsair or his patron to engrave the names on the back properly. And there was no known astronomical activity in Algiers before the Ottoman period.[287] Our Masʿūd, however, was competent in Arabic and in astrolabe-construction, as we can see from the inscription on the boss of the shackle and from the latitudes he used for his plate. Besides, if he made the additions in Algiers, there would have been no reason whatsowever not to add the name of Mecca and the names of the prayers.

The astrolabe is a testimonial to the lives and fates of three, perhaps only two individuals; indeed, on no other historical instrument are the lives and aspirations and fates of individuals so poignantly portrayed. One was a Jew, perhaps involved only in the laying out of the astronomical markings on the piece. The second, the person who did the Latin engraving, was maybe identical

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[287] See n. 278 above. In *Cairo ENL Survey*, p. 145 (no. F66), there is information on a late (17th-century?) recension for Algiers of the 14th-century astronomical tables of Ibn al-Shāṭir of Damascus (on whom see the article in *DSB*).

to the first, but if he was not, then he may have been a Spanish Christian, possibly a convert from Judaism. He seems to have died or been beset by some other disaster before he finished the piece. The other was a Muslim Arab, a *mudéjar*, who seems to have been planning to return to the Muslim world as religious duty behoved him, specifically to Algiers. He finished the astrolabe and certainly planned to take it with him.

There are still many questions surrounding this astrolabe to which it would be satisfying to know the answers. Part of the problem is that there are so few instruments with which we can compare this piece.[288] The most tantalizing questions relate to the person(s) who started to make it and the one named Masʿūd who finished it. All manner of scientific, technological, epigraphic and art-historical investigations will not necessarily bring us any closer to the answers. But there is hope that further research might cast more light on the provenance of this object, and this would be welcome, for it is surely one of the most interesting astrolabes surviving from the Middle Ages.

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[288] Other European instruments from medieval Spain have not fared well in the modern literature. As already noted, the oldest surviving European astrolabe, #3042, has been the object of much controversy, and two other important pieces from Catalonia, #416 and #3053, are not even published. General historians of science cannot take instruments seriously until the basic research has been done. Thus, for example, in Glick, "Jewish Contribution to Science in Medieval Spain", the choice of instruments used to illustrate that article was unfortunate: fig. 22 on p. 82 shows a medieval astrolabe with Hebrew inscriptions which is probably Italian (#159); fig. 21A on p. 88 shows a Renaissance astrolabe (#164) datable *ca*. 1480 and from Vienna, not from Spain as maintained by Gunther (see now **XVII-5**); and fig. 21B on p. 89 shows an unsigned, undated Maghribi or Andalusī astrolabe fitted with a most unusual Ottoman replacement rete (#3643).

APPENDIX A: LIST OF INSTRUMENTS CITED

Note: Each instrument has been assigned a number (here prefixed by #), continuing the tradition started by R. T. Gunther and upheld by Derek de Solla Price. The vast majority of the instruments listed below are described in the catalogue in preparation in Frankfurt. Various instruments mentioned only in passing are not listed here, and for these the reader must have recourse to Price *et al.*, *Astrolabe Checklist*. The star-positions on numerous individual astrolabes are investigated in Stautz, *Mathematisch-astronomische Darstellungen auf mittelalterlichen Instrumenten*.

#101 Unsigned, undated 10th-century astrolabe from Iraq, with purportedly medieval European markings on the back—Florence, Istituto e Museo di Storia della Scienza, inv. no. 1113—Gunther, *Astrolabes*, I, pp. 230-231 (no. 101: "The Astrolabe of Pope Sylvester II", already expresses reservations); García Franco, *Astrolabios en España*, pp. 131-160 (no. 3, an electrotype copy: "Astrolabio del siglo XIII, reproducción del de Alfonso el Sabio"); *Santa Cruz 1985 Exhibition Catalogue*, pp. 78-79 (no. "astrolabio de autor desconocido"); *Cádiz-Algeciras 1995 Exhibition Catalogue*, p. 60 ("Astrolabio de Alfonso X el Sabio"); *Florence MSS Catalogue*, p. 8, no. 2 ("La tradizione lo fa risalire a Carlo Magno."); and King, "Astronomical Instruments between East and West", p. 171 (introduces 19th-century faker for the markings on the back). See now **XIIIc-6**.

#103 Astrolabe by ʿAbd al-Karīm al-Miṣrī dated 625 H [= 1227/28], with later replacement rete (see **XIVd-2**)—Oxford, Museum of the History of Science, inv. no. IC 103—see Gunther, *Astrolabes*, I, pp. 233-236 (no. 103).

#104 Astrolabe by ʿAbd al-Karīm al-Miṣrī, made in Damascus in 633 H [= 1235/36]—London, British Museum, inv. no. OA 1855, 7-9.1—see Gunther, *Astrolabes*, I, pp. 236-237 (no. 104).

#106 Universal plate by Ibrāhīm al-Dimashqī, made in Cairo (?) in 699 H [= 1299/1300]—London, British Museum, inv. no. OA 1890, 3-15.3—see Gunther, *Astrolabes*, I, p. 238 (no. 106).

#107 Astrolabic plate made by Ḥasan ibn ʿAlī in Cairo in 681 H [= 1282/83]—Oxford, Museum of the History of Science, inv. no. IC 107—see Gunther, *Astrolabes*, I, pp. 239-240 (no. 107), and **Fig. 18** above.

#109 Astrolabe made by the Yemeni Sultan al-Ashraf in 695 H [= 1291]—New York, Metropolitan Museum of Art, inv. no. 91.1.535—see Gunther, *Astrolabes*, I, p. 243 (no. 109) and pl. LVIb, and the detailed description in King, "Yemeni Astrolabe", now in **XIVa**.

#110=#135 10th-century Andalusī astrolabe, with later markings by a European—London, British Museum, inv. no. OA+371—see Gunther, *Astrolabes*, I, p. 244 (no. 110), and p. 280 (no. 135), inadvertently listed twice; and King, "Oldest European Astrolabe", fig. 3.

#111 Astrolabe by Ḥāmid ibn Khiḍr al-Khujandī, made in Baghdad in 374 H [= 984/85]. with quatrefoil decoration on the rete—Kuwait, private collection—see the detailed description in King, "Kuwait Astrolabes", pp. 80 and 82-89, also the illustrations in *idem*, *Mecca-Centred World-Maps*, pp. 18-19, and now **XIIIc-9**.

#116 Astrolabe by Muḥammad ibn al-Ṣaffār of Toledo, dated 420 H [= 1029/30]—Berlin, Deutsche Staatsbibliothek, Preußischer Kulturbesitz, Orientabteilung, inv. no. 6567 (Sprenger 2050)—see the detailed description in Woepcke, "Arabisches Astrolabium"; Gunther, *Astrolabes*, I, pp. 251-252 (no. 116), based on Woepcke; and on the additional inscriptions, Maier, "Romanische Monatsnamen", B, p. 260. See here **Fig. 15**.

#117 Astrolabe by Ibrāhīm ibn Saʿīd al-Sahlī, dated Toledo, 459 H [= 1066/67]—Madrid, Museo Arqueológico Nacional, inv. no. 50762—see the detailed description in García Franco, *Astrolabios en*

España, pp. 229-235 (no. 12); and also Gunther, *Astrolabes*, I, pp. 252-253 (no. 117), and *Santa Cruz 1985 Exhibition Catalogue*, pp. 80-81 (colour illustrations of the front and back).

#123 Astrolabe by Ibrāhīm ibn Saʿīd, made in Valencia, 463 H [= 1070/71]—now in the Osservatorio, Rome—unpublished, see Gunther, *Astrolabes*, I, p. 263 (no. 123).

#130,134,139,153 Various astrolabes by al-Khamāʾirī of Seville *ca*. 1220—see Gunther, *Astrolabes*, I.

#134 See #130.

#135 See #110.

#137 Astrolabe with circus-figures on the rete, made in Syria by al-Sahl al-Nīsābūrī, datable between *ca*. 1180 and *ca*. 1280—Nuremberg, Germanisches Nationalmuseum, inv. no. WI 20—see the detailed descriptions in *Nuremberg GNM 1992-93 Exhibition Catalogue*, pp. 570-574 (no. 1.71); and *Paris IMA 1993-94 Exhibition Catalogue*, pp. 432-434 (no. 329). See now **XIVb-2**.

#137 *bis* See #550.

#139 See #130.

#140 The quintuply-universal astrolabe of Ibn al-Sarrāj, Aleppo, 729 H [= 1328/29]—Athens, Benaki Museum, inv. no. 13178—see Gunther, *Astrolabes*, I, pp. 285-286 (no. 140); King, *Studies*, B-IX; *Paris IMA 1993-94 Exhibition Catalogue*, pp. 434-435 (no. 330); and now **XIVb-5**. A book on this instrument by François Charette and the present author is forthcoming.

#153 See #130.

#154 Andalusī astrolabe by Muḥammad ibn Yūsuf ibn Ḥātim dated 638 H [= 1240/41]—Chicago, Ill., Adler Planetarium, inv. no. M-36—see Gunther, *Astrolabes*, I, pp. 300-301 (no. 154), misdated to 1747; and *Chicago AP Catalogue*, II (forthcoming). See here **Fig. 12**.

#158 Astrolabe with Hebrew incriptions, Bologna (?), *ca*. 1400 (?) (see no. #159)—London, British Museum, inv. no. 93 6-16 3—Gunther, *Astrolabes*, II, p. 304 (no. 158); *London BM Catalogue*, p. 113-114 (no. 328) and pl. LIIIa; and also Goldstein, "Hebrew Astrolabe". See also **Fig. XVII-4.1**.

#159 Degenerate astrolabe with Hebrew inscriptions, Bologna (?), *ca*. 1400 (?), with plates labelled for Bologna and Paris—Chicago, Ill., Adler Planetarium, inv. no. M-20—Gunther, *Astrolabes*, II, p. 304 (no. 159); Goldstein, "Hebrew Astrolabe"; and *Chicago AP Catalogue*, II, pp. 58-60 (no. 7). See also **Fig. XVII-4.2**.

#161 "Hispano-Mauresque" astrolabe, with "distinctly oriental appearance", no star-names on the rete, with plates for the climates and equinox at March 15—present location unknown, *ca*. 1930 in the collection of Sir J. Findlay—see Gunther, *Astrolabes*, II, p. 306 (no. 161).

#162 Catalan astrolabe from *ca*. 1300 with a rectangular frame and decorative quatrefoil on the rete—London, Society of Antiquaries—see Gunther, *Astrolabes*, II, pp. 306-309 (no. 162), and the detailed description in King & Maier, "London Catalan Astrolabe". See also **Fig. XVII-3.1**.

#163 A French astrolabe, not Spanish as claimed by Gunther.

#164 Astrolabe with quatrefoil decoration and plates for latitudes 40°, 42°, 44°, 45°, 48° and 50°, attributable to the Vienna school (the elongated horizontal form of the final *s* is very reminiscent of Hans Dorn of Vienna *ca*. 1480)—Chicago, Ill., Adler Planetarium, inv. no. M-28—see Gunther, *Astrolabes*, II, pp. 311-312 (no. 164, under Spanish astrolabes) and miniature reproduction of front on pl. LXX; Glick, "Jewish Contribution to Science in Medieval Spain", fig. 21A on p. 88; and *Chicago AP Catalogue*, II, pp. 49-52 (no. 4, again with the provenance as Spain). See now **XVII-5**.

#165 Astrolabe made in Saragossa in 1558—Oxford, Museum of the History of Science, inv. no. IC 165—see Gunther, *Astrolabes*, II, pp. 312-315 (no. 165) and pl. LXX.

#166 Italian astrolabe with plates for the climates—Oxford, Museum of the History of Science, inv. no. IC 166—see Gunther, *Astrolabes*, II, pp. 316-317 (no. 166).

#167 Medieval Italian (?) astrolabe—London, British Museum, inv. no. 67 7-5 22—see Gunther, *Astrolabes*, II, p. 317 (no. 167), and *London BM Catalogue*, p. 114 (no. 329).

#169 Italian non-standard astrolabe from *ca*. 1300, with markings only for latitude 24° (second climate), suggesting that this may be a 19th-century copy of such an instrument—Oxford, Museum of the History

of Science, inv. no. IC 169—see Gunther, *Astrolabes*, pp. 319-320 (no. 169); and the detailed description in King, "Italian Astrolabe", now in **XIIId**.

#190 Astrolabic plate for latitude 48;50° (Paris), 14th century (?)—London, Victoria and Albert Museum, inv. no. M. 128.1923—unpublished; see Gunther, *Astrolabes*, II, p. 349 (no. 190); *Instrument Directory*, p. 27, figs. 7A-B (front and back); also King, *The Ciphers of the Monks*, pp. 391-392.

#191 Composite medieval European astrolabe, with an Italian mater, Andalusī-style rete (reworked?), and plates for Saragossa and Paris—Oxford, Museum of the History of Science, inv. no. IC 191—Gunther, *Astrolabes*, II, pp. 340-341 (no. 191).

#198 Northern French astrolabe from *ca*. 1350 with luni-solar gear mechanism—London, Science Museum, inv. no. 1880.32—see Gunther, *Astrolabes*, II, p. 347 (no. 198), and King, *The Ciphers of the Monks*, pp. 398-399, 402-403, *etc*. (see p. 439).

#202 Picard astrolabe from *ca*. 1350 with numbers marked in monastic ciphers—private collection—see Gunther, *Astrolabes*, II, p. 349 (no. 202), and the detailed description in King, *The Ciphers of the Monks*, pp. 131-151 and 406-419. See also **Figs. XIIIa-10.3**.

#203 Illustrations of the rete and back of an astrolabe in the treatise *L'usaige de l'astrolabe* by Dominique Jacquinot, printed in Paris in 1545—see Gunther, *Astrolabes*, II, pp. 350-352 (no. 203).

#213 Highly unusual medieval astrolabe in iron, of uncertain date and provenance, with latitude grid around the ecliptic on the rete and inlaid silver illustrations of the zodiacal signs on the back—*ca*. 1930 in the possession of Whitney Warren; present location unknown—see Culver, "Early European Instruments", p. 34, for an illustration of the front, and Gunther, *Astrolabes*, II, pp. 361-362 (no. 213); Gunther's dating to the end of the 16th century is much too late.

#290 English astrolabe from *ca*. 1300 with highly-developed quatrefoil decoration on the rete—London, British Museum, inv. no. MLA SL54—see Gunther, *Astrolabes*, II, pp. 463-465 (no. 290). See also **Fig. XVII-3.7**.

#291 Unsigned English astrolabe dated 1326—London, British Museum, inv. no. 1909 6-17 1—see Gunther, *Astrolabes*, II, pp. 465-467 (no. 291); and *London BM Catalogue*, pp. 112-113 (no. 325), and pl. LI.

#292 English astrolabe signed "Blakenei" and dated 1342—London, British Museum, inv. no. 53 11-4 1—see Gunther, *Astrolabes*, II, pp. 468-469 (no. 292); and *London BM Catalogue*, p. 113 (no. 326) and pl. LII. See also **Fig. XVII-3.5**.

#293 Medieval English astrolabe with additional Hebrew inscriptions (owner's mark?) on the throne—London, Victoria & Albert Museum, inv. no. 1880.26—see Gunther, *Astrolabes*, pp. 469-471 (no. 293).

#300 Northern French (?) or English (?) astrolabe from *ca*. 1300—Oxford, Museum of the History of Science, inv. no. IC 300—see Gunther, *Astrolabes*, II, pp. 477-478 (no. 300), and King, "Oldest European Astrolabe", fig. 12. See here **Figs. 14** and **X-10.2a**.

#304 Unsigned, undated English astrolabe—Washington, D.C., National Museum of American History, inv. no. 316758—see Gunther, *Astrolabes*, II, p. 483 (no. 304) and pl. CXXXIV; and *Washington NMAH Catalogue*, pp. 13 and 150-151 (no. 304).

#416 Catalan astrolabe from *ca*. 1300 with a Y-shaped frame on the rete—Greenwich, National Maritime Museum, inv. no. ASTO552 = A21/1936-21C—see King & Maier, "London Catalan Astrolabe", pp. 694-695, n. 60, King, "Oldest European Astrolabe", fig. 14; and the forthcoming description by Koenraad van Cleempoel in *Greenwich Astrolabe Catalogue*. See also n. 16.

#420 Early medieval European astrolabe, perhaps the earliest after #3042, origin uncertain—Greenwich, National Maritime Museum, inv. no. ASTO558 = A27/1936-4C—illustrated in King, "Oldest European Astrolabe", fig. 9; see the forthcoming description by Koenraad van Cleempoel in *Greenwich Astrolabe Catalogue*.

#428=#625 French astrolabe from *ca*. 1300—Greenwich, National Maritime Museum, inv. no. ASTO570 = A39/NA1938-1661C—see *Greenwich Astrolabe Booklet*, p. 48, for an illustration of the front; and the forthcoming description by Koenraad van Cleempoel in *Greenwich Astrolabe Catalogue*.

#457 Medieval English astrolabe—Liège, Musée de la vie wallonne, inv. no. 400—unpublished; illustrated in Michel, *Traité de l'astrolabe*, pl. III.

#460 Astrolabe from the workshop of Jean Fusoris, Paris, *ca*. 1400, with inscriptions removed and replaced by 18th- or 19th-century Arabic inscriptions (probably in Egypt)—Antwerp, Nationaal Scheepvaartmuseum, inv. no. A.S. 43.9.127—see Michel, *Traité de l'astrolabe*, pl. IV; and *Brussels SG 1984 Exhibition Catalogue*, pp. 37-38 (no. 8).

#493 14th-century Italian astrolabe—Florence, Museo di Storia della Scienza, inv. no. 1107—detailed description in King, "Urbino Astrolabe", pp. 127-129; see also *idem*, "Star-Names on Three Medieval Astrolabes", pp. 320-323.

#546 14th-century French quatrefoil astrolabe—Paris, private collection—unpublished.

#548 14th-century Italian astrolabe with additional 15th-century markings by Henricus de Hollandia—Nuremberg, Germanisches Nationalmuseum, inv. no. WI 6—see *Nuremberg GNM 1992-93 Exhibition Catalogue*, II, pp. 578-581 (no. 1.74), and also **Figs. XIIIa-10.5a-e**.

#549 Unsigned astrolabe of the Vienna school dated 1457—Nuremberg, Germanisches Nationalmuseum, inv. no. WI 129—see *Nuremberg GNM 1992-93 Exhibition Catalogue*, II, pp. 582-586 (no. 1.75).

#550 German astrolabic plate dated 1468—Nuremberg, Germanisches Nationalmuseum, inv. no. WI 5—see Gunther, *Astrolabes*, I, pp. 280-281 (no. 137—confused!) and more especially *Nuremberg GNM 1992-93 Exhibition Catalogue*, II, pp. 589-592 (no. 1.77).

#555 Unsigned, undated astrolabe in the tradition of the Arsenius brothers—Nuremberg, Germanisches Nationalmuseum, inv. no. WI 1164—see *Nuremberg GNM 1992-93 Exhibition Catalogue*, pp. 598-600 (no. 1.82). See here **Fig. 11**.

#558 Early medieval European astrolabe of uncertain provenance—Nuremberg, Germanisches Nationalmuseum, inv. no. WI 282—see *Nuremberg GNM 1992-93 Exhibition Catalogue*, II, pp. 574-576 (no. 1.72).

#621 Composite medieval European (Italian?) astrolabe with a very early rim, rete and plates, and a back from an astrolabe with Hebrew inscriptions—Munich, Deutsches Museum, inv. no. 5178—see *Munich Astrolabe Catalogue*, pp. 161-176 (no. 2), also King, "Oldest European Astrolabe", fig. 13.

#625 See #428.

#640 Astrolabe presented by Regiomontanus to his patron Bessarion in 1462—private collection—see most recently King & Turner, "Regiomontanus' Astrolabe".

#1077 Astrolabe made in Fez by ʿUthmān ibn ʿAbdallāh al-Ṣaffār in 699 H [= 1299/1300]—Florence, Istituto e Museo di Storia della Scienza, inv. no. 1109—unpublished; see Mayer, *Islamic Astrolabists*, p. 84 and pl. IVb, and *Venice 1993-94 Exhibition Catalogue*, pp. 178-180 (no. 79).

#1099 Astrolabe made by Aḥmad ibn Muḥammad al-Naqqāsh in Saragossa in 472 H [= 1079/80]—Nuremberg, Germanisches Nationalmuseum, inv. no. WI 353—see *Granada-New York 1992 Exhibition Catalogue*, pp. 376-377 (no. 120); and *Nuremberg GNM 1992-93 Exhibition Catalogue*, II, pp. 568-570 (no. 1.70).

#1148 Astrolabe by Muḥammad ibn Fattūḥ al-Khamāʾirī dated 628 H [= 1230/31], with later inscriptions in a dialect of Northern Spain—Cairo, Museum of Islamic Art, inv. no. 15371—unpublished; see Maier, "Romanische Monatsnamen", A, pp. 247-249.

#2041 Medieval French (?) astrolabe with zoomorphic features on the rete—Oxford, Museum of the History of Science, inv. no. 57-84/173 (Billmeir 173)—unpublished; the front and back are illustrated in Poulle, *Instruments du Moyen Age*, pp. 12 and 14. See also **Fig. XIIIc-9n**.

#2572 Andalusī astrolabe by Muḥammad al-Sahlī dated 483 H [= 1090/91] with a replacement rete bearing Hebrew inscriptions—Washington, D.C., National Museum of American History, inv. no. 318178—see *Washington NMAH Catalogue*, pp. 174-177 (no. 2752); Goldstein & Saliba, "Hispano-Arabic-Hebrew Astrolabe"; and Lacarenza, "Il ragno ebraico dell'astrolabio di Ibn al-Sahlī".

#3042 Astrolabe from 10th-century Catalonia—Paris, Institut du Monde Arabe, inv. no. AI 36-31—see King, "Oldest European Astrolabe", and other papers in Stevens et al., *Oldest Latin Astrolabe*. A fine

illustration of the front is in *Cádiz-Algeciras 1995 Exhibition Catalogue*, p. 187. See also **XIIIa-9.1** (illustrated).

#3053 Astrolabe signed by Petrus Raimundus of Aragon, made in Barcelona and dated 1375—Boston, Mass., Museum of Fine Arts, inv. no. 88.654—see n. 16 for a description in Catalan, to appear; the front is illustrated in King, "Oldest European Astrolabe", fig. 16. See also **Fig. XIVb-6.1**.

#3058 14th-century French quatrefoil astrolabe with an additional plate for London and Paris and a later signature "I LOND", surely for "John of London", but which one??—Greenwich, National Maritime Museum, inv. no. A60/NA66-12—see the forthcoming description by Koenraad van Cleempoel in *Greenwich Astrolabe Catalogue*.

#3595 Astrolabe made in 830 H [= 1426/27] by Muḥammad ibn Jaʿfar al-Kirmānī for Ulugh Beg (his name has been removed from the dedication)—Copenhagen, Davids Samling, inv. no. D 25/1986—unpublished; see *Copenhagen DS Catalogue*, p. 214, King, "Strumentazione", pp. 161 and 165; *idem*, *Mecca-Centred World-Maps*, pp. 106-108; and now **XIVd-1** (illustrated).

#3622 Unsigned astrolabe from Cordova, dated 446 H [= 1054/55], with later Catalan additions—Cracow, Jagiellonian Museum, inv. no. 4037-35/V—see the detailed description in Maier, "Ein Astrolab aus Córdoba", and also **Fig. XVI-10.3**.

#3643 Unsigned, undated Maghribi or Andalusī astrolabe with unusual Ottoman replacement rete—Washington, D.C., National Museum of American History, inv. no. 316753—see Gunther, *Astrolabes*, I, p. 302 (no. 84A); and *Washington NMAH Catalogue*, pp. 177-179 (no. 3643).

#3650 Mater and plates by Muhammad ibn al-Ṣaffār, dated 417 H [= 1026/27] (the rete is a replacement)—Edinburgh, Royal Scottish Museums, inv. no. T1959-62—not properly published; see *Instrument Directory*, p. 27, fig. 6 (front only).

#3906 Medieval astrolabe with inscriptions in Hebrew—Paris, private collection—see Bandeira Ferreira, "Astrolábio hebraico", and also Goldstein, "Hebrew Astrolabe".

#3915 Astrolabe with inscriptions in Judaeo-Arabic, al-Andalus or the Maghrib, *ca*. 1300 (?)—London, N. D. Khalili Collection, inv. no. SC 1158—see *Christie's Amsterdam 15.12.1988 Catalogue*; *London Khalili Collection Catalogue*, II, pp. 214-217 (no. 124), and King, "Review", col. 253. See here **Fig. XVII-3.2**.

#4024 An illustration of a 10th-century Andalusī astrolabe signed by Khalaf ibn al-Muʿādh, found in a Latin manuscript—MS Paris BN lat. 7412, fols. 19v-23v—see most recently Kunitzsch, "10th-Century Andalusī Astrolabe", and the bibliography there cited. See also **Figs. XIIIa-9.2a-b**.

#4029 Unsigned astrolabe from 14th-century Yemen—Paris, Institut du Monde Arabe, inv. AI 86-15—see *Paris IMA Catalogue*, pp. 89-90 (no. 5), and now **XIVa-A1**.

#4036 Astrolabe by Ḥasan ibn ʿUmar al-Naqqāsh, dated 681 H [= 1282/83], with Coptic numerals and silver inlay throughout—Istanbul, Turkish and Islamic Archaeological Museum, inv. no. 2970—unpublished; the front is illustrated in Nasr, *Islamic Science*, p. 120, pl. 73; the geographical gazetteer is discussed in King, *Mecca-Centred World-Maps*, pp. 76-78 and 600-602. See **Figs. 18** and **XIIIc-3.2e**.

#4046 Unsigned undated Maghribi astrolabe, datable *ca*. 1600—Qatar, National Museum—see *Geneva MAH 1985 Exhibition Catalogue*, pp. 284-285 (no. 296), and the more detailed description in *Sotheby's 16.10.1997 Catalogue*, pp. 70-73 (lot 25).

#4182 Astrolabe made in Fez in 719 H [= 1319/20] by Muḥammad ibn Qāsim al-Qurṭubī—in 1971 in the possession of M. Dagron of Paris; present location unknown—unpublished. See here **Figs. 13a-b**.

#4217 Astrolabe made in Granada in 886 H [= 1481/82] by Muḥammad ibn Zawāl (??)—Granada, Museo Arqueológico Provincial, inv. no. 12115—see Mendoza Eguaras, "Astrolabio de Granada", and *Madrid MAN 1992 Exhibition Catalogue*, p. 227 (no. 44).

#4307 Astrolabe by Maḥmūd ibn Jalāl al-Kirmānī dated 833 H [= 1429/30]—present location unknown — brief description in *Sotheby's London 16.12.2003 Catalogue*, pp. 40-41 (lot 56).

#4506 Italian astrolabe bearing the initials "KP" and dated Urbino, 1462—Moulins, Musée Départemental, stolen—published in detail in King, "Urbino Astrolabe", pp. 130-132; see also *idem*, "Star-Names on Three Medieval Astrolabes", pp. 323-324. Illustrations also in **Figs. XIIIa-10.4a-c**.

#4509	Italian astrolabe from *ca*. 1300 with a replacement plate from a Byzantine astrolabe and additional markings in Hebrew—private collection, acquired at Sotheby's of London on 18.6.1986 (lot 125)—see *Amsterdam NK 1990 Exhibition Catalogue*, p. 101 (no. 186) and p. 106.
#4523	Astrolabe made by Antonius de Pacent in Lanzano in 1420—Germany, private collection—see the detailed description in Stautz, "Ein Astrolab aus dem Jahr 1420".
#4560	The astrolabe under discussion—private collection—see n. 1.
#4561	A 16th-century Spanish universal astrolabe—formerly private collection, acquired in 1999 by the Museo Nacional de Ciencia y Tecnología, Madrid—see the detailed description in Moreno *et al*., "Spanish Astrolabe".

APPENDIX B: THE EARLIEST EUROPEAN ASTROLABES FROM SPAIN AND FRANCE, LISTED CHRONOLOGICALLY BY REGION

Note: For lists of the 40-odd earliest Islamic astrolabes and some 35 of the earliest European astrolabes see King, "Oldest European Astrolabe", pp. 387-391. A more extensive list is on the website identified in **XVIII**.

Catalonia (10th century):

- ❖ #3042 (the so-called "Carolingian astrolabe")

Uncertain provenance:

- ❖ #161 (clearly early, Spain?/France?, plates serve the seven climates)—present location unknown!
- ❖ #420 (12th/13th century?, Spain?/France?, plates serve the seven climates)
- ❖ #191 (a composite piece, date(s) uncertain, Italian mater, rete entirely Islamic in design, original plates for Saragossa, Toulouse and Paris)

Catalonia (11th-15th century):

- ❖ #162 (with rectangular frame within rete, *ca*. 1300)
- ❖ #416 (with Y-shaped frame within rete, *ca*. 1300)
- ❖ #3053 (signed by Petrus Raimundus, dated Barcelona, 1375)

Central or Northern Spain, excluding Catalonia (12th-15th century):

- ❖ #4560 (the astrolabe with Latin and Arabic and Hebrew inscriptions described here, probably 14th century)

Southern Spain or the Maghrib (*ca*. 1300 (?)):

- ❖ #3915 (astrolabe with Judaeo-Arabic inscriptions, with rete design closely related to that on #162, *ca*. 1300)

Southern France:

- ❖ Ø

Northern France (prior to *ca*. 1400—selected):

- ❖ #198 (14th century, with luni-solar gear mechanism)
- ❖ #202 (14th century, Picardy, featuring monastic numerical ciphers)
- ❖ #300 (13th/14th century, Northern France and/or Southern England, includes plates which would serve Paris and London)
- ❖ #428 (*ca*. 1300, lions on throne, "Hispano-mauresque" rete, plates for 14 latitudes between 15° and 48° Paris, including 43° Tolosa, that is, Toulouse)
- ❖ #2041 (14th century, *fleur-de-lys* design on throne, zoomorphic features on rete, plates for 10 latitudes between 22° and 48° with no localities mentioned, most probably French, although FEBROARIUS suggests Italian influence)
- ❖ #190 (14th century (?), quatrefoil rete, single astrolabic plate with markings for 48;50°, that is, Paris)

There are some 30 known astrolabes from the workshop of Jean Fusoris in Paris *ca*. 1400 (*e.g*., #192, #193, #194 in Gunther) or Fusoris-type instruments (including some predating Fusoris),

which do not concern us here. The best publication on French astrolabes of this type is Glasemann, "Zwei mittelalterliche französische Astrolabien". Likewise, there are numerous quatrefoil astrolabes that could be French and prior to *ca*. 1400 (such as #3058), but their provenance is not certain.

Notes: Gunther's "Spanish" #161 is a composite piece, and at least the mater is Italian. His "Spanish" #163 is French.

Part XVI

The geographical data on early Islamic astronomical instruments

Dedicated to John North in 1999

DEDICATION,
ACKNOWLEDGEMENTS AND NOTES TO THIS VERSION

For many years now I have not ceased to wonder at my prolific colleague John North. Not only has he set the study of astronomy in the English Middle Ages on a firm basis, with his monumental studies of Richard of Wallingford and Geoffrey Chaucer, but he has also contributed a series of important studies to the history of astronomy and astrology from Antiquity through to the Renaissance and beyond to modern cosmology. It was therefore a pleasure to contribute to his *Festschrift*. The first version of this study was first published as "Bringing Astronomical Instruments Back to Earth—The Geographical Data on Medieval Astrolabes (to *ca*. 1100)", in *Between Demonstration and Imagination: Essays in the History of Science and Philosophy Presented to John D. North*, Arjo Vanderjagt and Lodi Nauta, eds., Leiden: E. J. Brill, 1999, pp. 3-53.

My research on medieval instruments was supported by grants from the Deutsche Forschungsgemeinschaft, which support is gratefully acknowledged. It is a pleasure to thank Franćois Charette for his critical reading of various early drafts of this study, and Kurt Maier for his improvements to the consistency of the penultimate version.

In the original version (pp. 16-17), after a discussion of the geographical data on the Andalusī astrolabe #117, I added a note that turned out to be absurd about the origin of the distinctive latitudes for cities in al-Andalus, such as 39;52° for Toledo, and associated lengths of daylight and nighttime. I reproduce it here:

> "*Added in proof*: In January, 1999, I stumbled quite by chance across one of the sources of some of these geographical data. In the treatise on the *lámina universal* in the late-13th-century *Libros del saber de astronomía* of King Alfonso el Sabio, there is a geographical table for 21 localities in al-Andalus, as well as Mecca and Medina. The table gives the latitudes, as well as the lengths of the longest day and shortest days—see Appendix 2c. For Toledo we find, for example, 39;52°, the distinctive value noted above. Note also that on #117 the shortest days are also given, precisely as in this table. The original Arabic treatise was by the celebrated astronomer Ibn al-Zarqāllu (see *DSB*), and the table is dated 1067 A.D. (see King, *Islamic Astronomical Instruments*, VII, pp. 253-254)."

As my friend and colleague Professor Julio Samsó was happy to point out to me, the information on latitudes in the published version of the *Libros del Saber* was *added by the editor Rico y Sinobas from the very same astrolabe (#117) that I had been citing*! So we still do not know who first derived these values.

Another absurdity, that I found myself, relates to the Oxford astrolabe #3 made in Isfahan in 374 H, and my completely crazy conclusions (p. 9):

> "When an instrument made in Isfahan in the 10th century (#3), with markings for 30°,

32°, 33°, 36° and also 42°, fails to have a plate for 33° (Baghdad), we should bear in mind what the Shīʿī Buwayhids thought of the Sunnite Abbasids, namely, not much."
Somehow, the latitudes recorded here are unrelated to the astrolabe in question. One page of notes misplaced from a description of another astrolabe? The latitudes for the plates are corrected here and in **XIIIc-10**.

The version of this study published in the *Festschrift* for John North was devoid of diacritical markings, and the bibliographical abbreviations were removed from the bibliography without the entries being reorganized alphabetically, thus making it extremely difficult for readers to find out what the abbreviations meant. The version presented here is updated from the original text submitted to the editors.

TABLE OF CONTENTS

1 Introductory remarks

> "This is the side for latitude 66;25°, which is the end of the seventh climate [*sic*] and the northern limit of the inhabited part of the earth. What lies beyond is desolate and unknown. I have engraved these markings in order to ponder the power of Almighty God and (no less) because of the need of the person viewing (these markings) of a modest knowledge of astronomy, so I engraved the 24 equal hours (which is the maximum length of daylight at that latitude)." Inscription on one of the plates of an unsigned astrolabe made in Cordova in the year 446 H [= 1054/55] (#3622)—see **Fig. 10.3**.

The astronomical instruments of the Islamic and Christian Middle Ages constitute a veritable gold-mine of historical information that until recently had barely been tapped.[1] Thus, for example, we find new mathematical solutions to astronomical problems rendered graphically,[2] artistic developments related to astronomical and/or cultural or religious criteria,[3] linguistic clues to provenance and later fate,[4] problems relating to positions of stars on astrolabe retes,[5] and unusual number-notations used to mark scales.[6] In particular, a wealth of information can be gained from the geographical data explicitly or implicitly to be found on these instruments, and the purpose of this study is to survey the data from the earliest such instruments—for convenience choosing a closing date of *ca*. 1100[7]—and offer some interpretations of them. For

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[1] For a new introduction to the sources see King, "Astronomical Instruments between East and West" (Islamic and European), and now **X** (Islamic). The main research tools of the past are Gunther, *Early Science in Oxford*, II, and *idem*, *Astrolabes* (deals with Islamic and European astrolabes, long outdated); Mayer, *Islamic Astrolabists* (still the best source on Muslim instrument-makers—see below); and Price *et al*., *Astrolabe Checklist* (computer-sorted data-base with one line of information on each known astrolabe). There are also several museum catalogues of widely-varying quality and scope. For the future we shall have Brieux & Maddison, *Répertoire*, listing Eastern makers alphabetically with brief descriptions of their instruments (long promised but still not published), and a catalogue currently being prepared in Frankfurt containing detailed descriptions of all Islamic and European instruments to *ca*. 1550 arranged chronologically by region (announced with much enthusiasm but still a long way from being publishable—see King, "Instrument Catalogue in Preparation", A-C, and now **XVIII**).

[2] A preliminary discussion is in North, "Graphical Representation of Functions". More examples were presented by François Charette in his contribution "Numbers and Curves: the Graphical Representation of Functions in Islamic Astronomy" to the XXth International Congress of the History of Science, Liège, July, 1997. What is perhaps the most spectacular example from a mathematical point of view (if not from a graphical point of view—it is simply a circle cunningly situated) is described in Puig, "al-Zarqālluh's Graphical Method".

[3] Two examples on the retes of astrolabes are the quatrefoil and the bird's head for Vega, which both seem to be Byzantine in origin. See King, "Astronomical Instruments between East and West", p. 170, and *idem* & Maier, "London Catalan Astrolabe", pp. 680-683 (*ad* #162).

[4] See Maier, "Romanische Monatsnamen", A-B; *idem*, "Astrolab aus Córdoba"; and King & Maier, "London Catalan Astrolabe". In these studies, vernacular forms of the Latin and Romance month-names, vernacular forms of Latin star-names, and basically any available linguistic straw that can be grasped are used to pinpoint the provenance of instruments, or—in the case of medieval Latin additions to Islamic instruments—the location of their mutation.

[5] See Stautz, "Die früheste Formgebung der Astrolabien", and *idem*, *Mathematisch-astronomische Darstellungen auf mittelaterlichen Instrumenten*. A particularly interesting instrument (#4523), on which ecliptic and equatorial coordinates have been confused, is discussed in *idem*, "Astrolab aus dem Jahr 1420".

[6] See Destombes, "Astrolabe Carolingien", pp. 2-4, and King, "The Oldest European Astrolabe", pp. 371-372, on the alphanumerical notation found on a 10th-century astrolabe from Catalonia (#3042). The monastic number-notation found on one 14th-century Northern French astrolabe (#202) is also attested in some two dozen medieval manuscripts and was known to a series of Renaissance authors: see King, *The Ciphers of the Monks*.

[7] This limit has the advantage that amongst European instruments I need consider only the 10th-century Catalan astrolabe (#3042), with sporadic references to others with plates for the climates. I hope some day to prepare studies similar to this one dealing with Islamic instruments after *ca*. 1100, and European instruments after *ca*.

the latter task, we are fortunate to have the data-base of coordinates from some 70-odd medieval Islamic geographical tables published by Ted and Mary Helen Kennedy.[8] These data are presented in **App. A**, and the instruments from which they are extracted, listed in **App. B**, which happen to all be astrolabes,[9] belong to the following categories:

1 **Byzantine:** A single complete astrolabe dated 1062, and a plate from another.
2 **Early Eastern Islamic:** astrolabes from *ca*. 750 to *ca*. 1100, mainly Baghdad (14 pieces), then Isfahan (3 pieces).
3 **Early Western Islamic:** astrolabes from *ca*. 900 to *ca*. 1100, mainly al-Andalus (18 pieces).
4 **Earliest European:** A single astrolabe from 10th-century Catalonia representing a hypothetical Roman tradition and also displaying some Islamic influence; and various selected astrolabes from before *ca*. 1300.

It is the plates of the astrolabes, serving different latitudes, which provide the kind of information we are looking for, together with occasional horary quadrants for specific latitudes on the backs of the astrolabes.[10] With one notable exception (see below), there are no gazetteers on these early instruments giving the coordinates of a series of localities, such as we find on later Islamic astrolabes.[11] But we are witness to a deliberate and successful effort to make the instruments universal,[12] that is, useful in "the whole world".

1300. An investigation of the star-names and the selection of stars on astrolabe retes would also be worthwhile.

[8] Listed as Kennedy & Kennedy, *Islamic Geographical Coordinates*. A grand total of 12,000 entries comprising source, place-names, longitudes and latitudes is presented according to the four different arrangements. The corpus is currently being updated by Mercè Comes in Barcelona. A similar undertaking for medieval European coordinates would be worthwhile. Various published tables are reprinted in *Islamic Geography*, vol. 23 (1992): *European Geographical Tables Based on the Arabic Tradition ...* . It is of considerable interest to compare the data in two 15th-century European lists, one English, the other Italian, published together in North, *Horoscopes and History*, pp. 186-195.

[9] The best introduction to the astrolabe is still North, "The Astrolabe". However, as I took pleasure in telling John some years ago, his illustration of an exploded astrolabe with two plates is inaccurate—there should be three plates, which, together with the mater, provide seven surfaces for the climates. On the medieval Islamic reports and fantasies about the invention of the astrolabe and its introduction in the Islamic world see King, "The Origin of the Astrolabe according to the Medieval Islamic Sources", now in **XIIIe**.

[10] These were invented in Baghdad in the early 9th century: see King, "al-Khwārizmī", pp. 30-31; Charette & Schmidl, "al-Khwārizmī on Instruments", pp. 157-158 and 182-183; and also **X-6.3**, **XI-4.1**, and **XIIIc-8.1** and **9**.

[11] The gazetteer on #3 is a later addition. For a much later example, see Morley, "Astrolabe of Shāh Ḥusayn", pp. 22-26. This and numerous other gazetteers are investigated in King, *Mecca-Centred World-Maps*, pp. 170-186.

[12] There was serious interest in universal solutions to problems of spherical astronomy and mathematical geography in the Islamic Middle Ages, whose origins are to be detected already in Greek science. Some spectacular new "universal solutions" are presented in Charette, "Najm al-Din's Monumental Table", and King, *Mecca-Centred World-Maps*. See now the new versions of King, "Universal Solutions", in **VIa-b**.

[13] Thus, for example, the three makers named al-Iṣfahānī (#3 and #122, the former made by two brothers) seem indeed to have worked in Isfahan. However, as we shall see, al-Khujandī made his astrolabe (#111) neither in nor for Khujand, whence his family hailed, nor in or for Rayy, where he is known to have worked, but rather (perhaps in or at least) for Baghdad. On these instruments, see now **XIIIc**. On this kind of problem see also King & Turner, "Regiomontanus' Astrolabe", pp. 181-182 and 197-198, on #640, which bears an inscription implying that it came into being in Rome, whereas it was probably made in Vienna.

Most of the early Islamic astrolabes are signed; on the other hand, medieval European astrolabes before *ca*. 1400 are mainly unsigned. For the Islamic pieces these signatures, often geographically bound,[13] together with distinctive regional rete-design patterns and the geographical information derived from the plates, provide a reasonably secure geographical location for their fabrication. For the European astrolabes, with no signatures and without our having much control over regional trends in design, ascertaining the provenance has until recently often been a matter of guesswork, some of it with incorrect results.[14] Thus in this study of mainly Islamic materials it is the inherent interest of the data on the plates that is our concern, rather than the use of these data to establish the provenance of the instruments.

2 The seven climates

The earliest astrolabes bearing inscriptions in Greek (2^{nd}?-8^{th}? centuries)—alas not one is extant—were provided with seven sets of markings for the seven climates of Antiquity (see **Fig. 2.1**), so as to render them universal.[15] The middles of the climates (hereafter C1-C7) are defined by the lengths of maximum daylight in hours, thus:

C1	C2	C3	C4	C5	C6	C7
13^h	$13^1/_2$	14	$14^1/_2$	15	$15^1/_2$	16

and the beginnings and ends of the climates are appropriately defined by $^1/_4$ hour less or more than the lengths at the middle.

Quite by chance certain localities of significance in the history of ancient and/or medieval astronomy lie close to the midpoints of the climates, namely: the Yemen (C1); Syene (modern Aswan) (C2); Alexandria / Cairo (C3); Rhodes / Aleppo / Rayy (near modern Tehran) (C4); Constantinople / Catalonia (C5); the Po Valley (C6); and Paris / Vienna / Nuremberg (C7). This fortunate situation partly accounted for the popularity of the climates amongst medieval instrument-makers, Muslim and Christian alike. Indeed, the climates are of paramount importance for understanding the geography of medieval Islamic and European astrolabes and other instruments, and they have not received the attention they deserve in modern writings either on medieval geography or medieval instrumentation.[16]

Since the climates are defined in terms of the length of longest daylight, they are dependent

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[14] This is not to belittle Gunther's monumental achievement. But we may note, for example, that his no. 163 listed as Spanish is French, and his no. 173 listed as Italian is German. His no. 169 was listed as Sicilian because he calculated the latitude of the only astronomical markings as 39°, whereas, in fact, it is 24°: this piece is nevertheless not Syenian but indeed Italian, although not necessarily Sicilian. In fact it is a copy of a special universal astrolabe with plates for each of the climates (see next note) in which the maker contented himself with markings for just one climate, namely, the second. See further King, "Italian Astrolabe", now in **XIIId**. There are many pieces for which Gunther offers no provenance but on which there is implicit geographical data.

[15] See, for example, Gunther, *Astrolabes*, pp. 65 and 83, for the relevant passages in the treatises of Philoponus (*ca*. 530) and Severus Sebokht (before 660). On the climates in Antiquity the standard source is Honigmann, *Die sieben Klimata*; see also Neugebauer, *HAMA*, II, pp. 725-733. The climates in the Islamic sources are treated in the article "Iḳlīm" by André Miquel in EI_2, but the most useful study is Dallal, "Al-Bīrūnī on Climates".

[16] The explicit and implicit use of the climates on Islamic and European instruments well into the Renaissance is noted in King, "Astronomical Instruments between East and West", especially pp. 152 and 168-169, and also *idem*, "Nuremberg Astrolabes", I, pp. 107 and 111. There is a lot more on this subject that needs to be said.
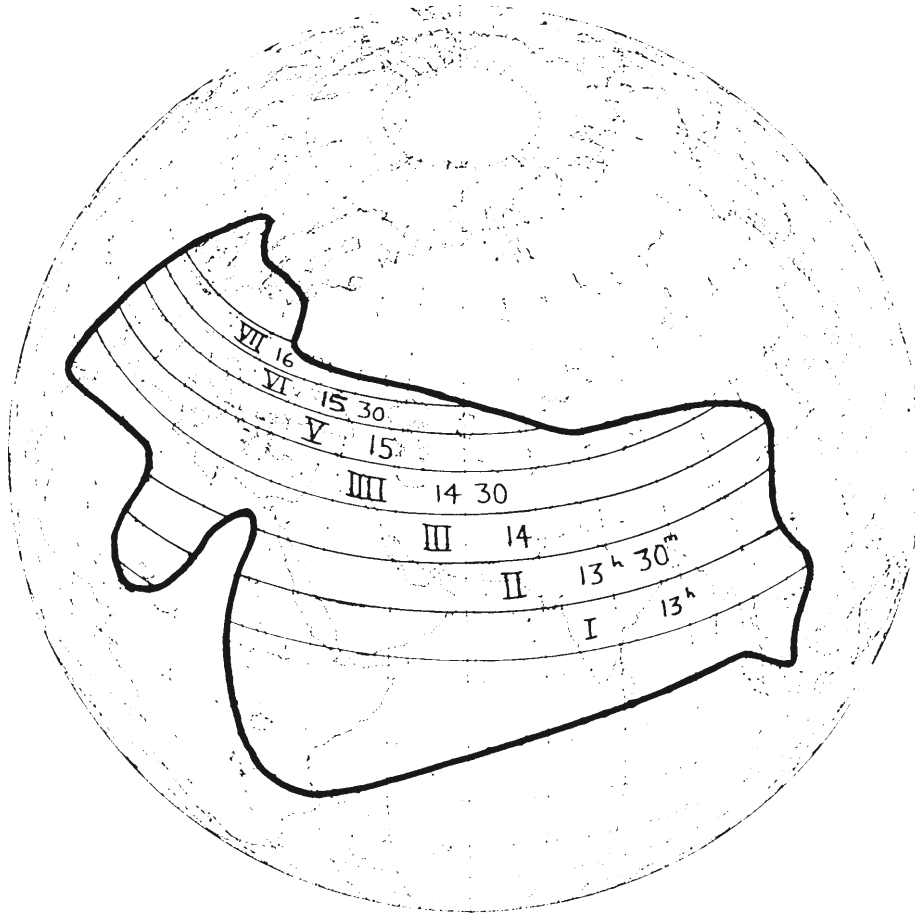
Fig. 2.1 The climates of Antiquity shown within the boundaries of the world as known to Ptolemy. The influence of the climates in medieval geography, astronomy, and instrumentation has been much underestimated in modern scholarship. [Courtesy of a student at Frankfurt University who left this with me without leaving his name.]

on the value assumed for the obliquity of the ecliptic, which changes over the centuries. Ptolemy's value was 23;51,20° and the latitudes he gives for the climates are based on it. Muslim astronomers commissioned by the Caliph al-Maʾmūn in the early 9th century measured the obliquity anew and came up with values of 23;33° and 23;35°;[17] the latitudes of the climates would of necessity be different—see **Table 1**[18]—although the Ptolemaic tradition was not abandoned forthwith, for most Muslim astrolabists in our period, and even some Safavid and

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[17] For values used by Muslim astronomers see the *EI*2 article "Minṭaḳat al-burūdj" [= zodiac] originally by Willy Hartner, updated by Paul Kunitzsch, especially VII, p. 86. Determinations of the obliquity were of course related to determinations of the local latitude.

[18] It is a pleasure to thank my colleague Dr. Benno van Dalen for compiling this table. Years ago, I could have generated such tables myself (using Fortran or Basic), but I no longer can do this (the more recent software tends to confuse me). See also n. 23 below.

TABLE 1
The latitudes (ϕ) of the midpoints and boundaries of the seven climates (C1-C7), defined in terms of the length of maximum daylight (D), for different values of the obliquity of the ecliptic (ε)

C	D	ε / 24°	23;51	23;35	23;33	23;31	23;30	23;28
	$12;45^{h}$	12;25°	12;30	12;39	12;40	12;42	12;42	12;43
C1	**13; 0**	**16;20**	**16;27**	**16;39**	**16;40**	**16;42**	**16;43**	**16;43**
	13;15	20; 6	20;14	20;28	20;30	20;31	20;32	20;33
C2	**13;30**	**23;40**	**23;49**	**24; 5**	**24; 7**	**24; 9**	**24;10**	**24;11**
	13;45	27; 1	27;11	27;29	27;31	27;33	27;35	27;36
C3	**14; 0**	**30;10**	**30;21**	**30;40**	**30;42**	**30;45**	**30;46**	**30;47**
	14;15	33; 6	33;17	33;37	33;40	33;42	33;44	33;45
C4	**14;30**	**35;50**	**36; 1**	**36;22**	**36;25**	**36;27**	**36;28**	**36;30**
	14;45	38;21	38;33	38;54	38;57	38;59	39; 1	39; 2
C5	**15; 0**	**40;41**	**40;53**	**41;14**	**41;17**	**41;20**	**41;21**	**41;22**
	15;15	42;50	43; 2	43;24	43;26	43;29	43;30	43;32
C6	**15;30**	**44;49**	**45; 1**	**45;22**	**45;25**	**45;28**	**45;29**	**45;31**
	15;45	46;38	46;50	47;12	47;15	47;17	47;19	47;20
C7	**16; 0**	**48;19**	**48;31**	**48;53**	**48;55**	**48;58**	**48;59**	**49; 1**
	16;15	49;52	50; 4	50;25	50;28	50;31	50;32	50;33

Note on the values of ε: Indians: 24°; Ptolemy: 23;51° (rounded); Muslim astronomers (9th and 14th centuries): 23;33°; Muslim astronomers (9th century and thereafter): 23;35°; al-Ṭūsī (*ca*. 1250) and Ibn al-Shāṭir (*ca*. 1350): 23;31°; Ulugh Beg (*ca*. 1425): 23;30° (rounded); Ottoman astronomers (16th century and thereafter): 23;28°.

Ottoman astrolabists centuries later, used, wittingly or not, Ptolemy's value.[19] The latitudes of the climates rounded to the nearest degree are:

16° 24° 30° 36° 41° 45° 48°.

We find the climates represented explicitly or almost so on the very earliest surviving Eastern Islamic astrolabes (#3702—8th century—see **XIIIb**), a solitary Abbasid plate (#109—10th century?—see **XIIIc-10b**) and the very earliest known Western Islamic astrolabe (#4042—10th century?—see **Fig. 2.2**), as well as some of the earliest European astrolabes (#161, #166, #167, #589, *etc*.).[20] Even on later ones (such as #202), they are often there implicitly.[21]

3 Traces of the climates

On the other hand, the only surviving Byzantine astrolabe (#2—dated 1062—see **XIIIa-4** and **Fig. 3.1**), no longer bears markings for the seven climates, but rather for Rhodes at latitude 36°

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[19] The sources, presumably originally textual, for the lengths of daylight corresponding to specific latitudes on Islamic astrolabe plates have not been identified. See, however, King, *Mecca-Centred World-Maps*, pp. 75-76, on a 13th-century table displaying the maximum length of daylight for the latitudes of some 50-odd localities, found in a Persian treatise on the use of the astrolabe.

[20] Some people could not resist modifying these into a more pleasing arithmetical array, namely: 15°—23°—30°—36°—41°—45°—48° (see #161). And others put C1 at 12°, corresponding to the beginning rather than the middle of that climate (see #166).

[21] This has plates for latitudes: 24°, 30°, 36°, 41°, 45°, 48°, and because it was made in Picardy, also 50° and 51°.
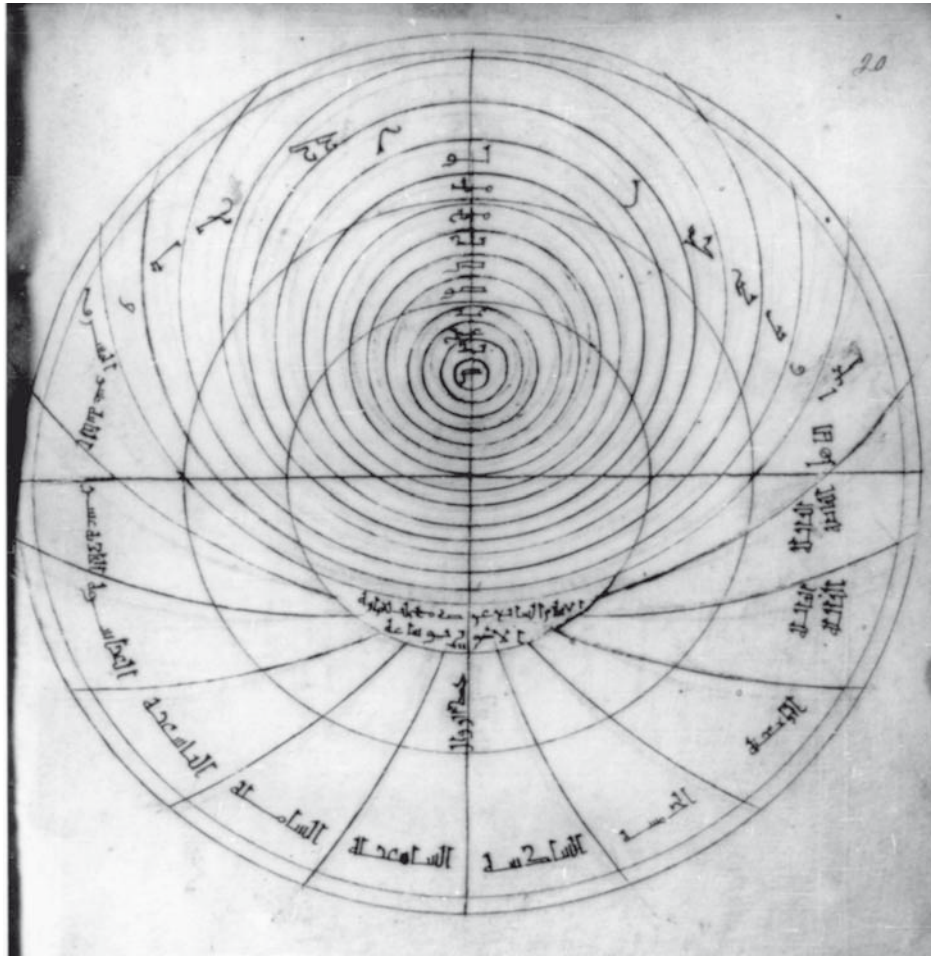
Fig. 2.2: An Andalusī astrolabe, signed by one Aḥmad ibn Muʿādh, served as the basis for a set of illustrations penned by a European in the 10th century (#4042). See **Figs. XIIIa-9.2a-b** for the rete and back. The mater and the three plates are marked for each of the seven climates. This plate serves the seventh climate. See further Kunitzsch, "10th-Century Andalusī Astrolabe", on the illustrations. [From MS Paris B.N.F. lat. 7412, fol. 20v, courtesy of the Bibliothèque Nationale de France.]

associated with C4, and for Hellespont and Byzantium at latitudes 40° and 41° both associated with C5. A carelessly-engraved solitary medieval plate with Greek letters for the altitude arguments (#4509) serves latitude 43°. On a Greek astronomical ring-dial dating from the period 250-350 A.D. excavated at Philippi in 1965, the latitudes served are 31° for Alexandria, 36° for Rhodes, $41^1/_3$° for Rome, and 45° for Vienne in the Rhone Valley.[22]

The notion of replacing the climates by specific latitudes is thus already an innovation of late Antiquity; certainly it influenced early Eastern Islamic instrumentation. For although, as

[22] On this splendid piece, see the preliminary discussion in Gounaris, "Anneau astronomique antique".
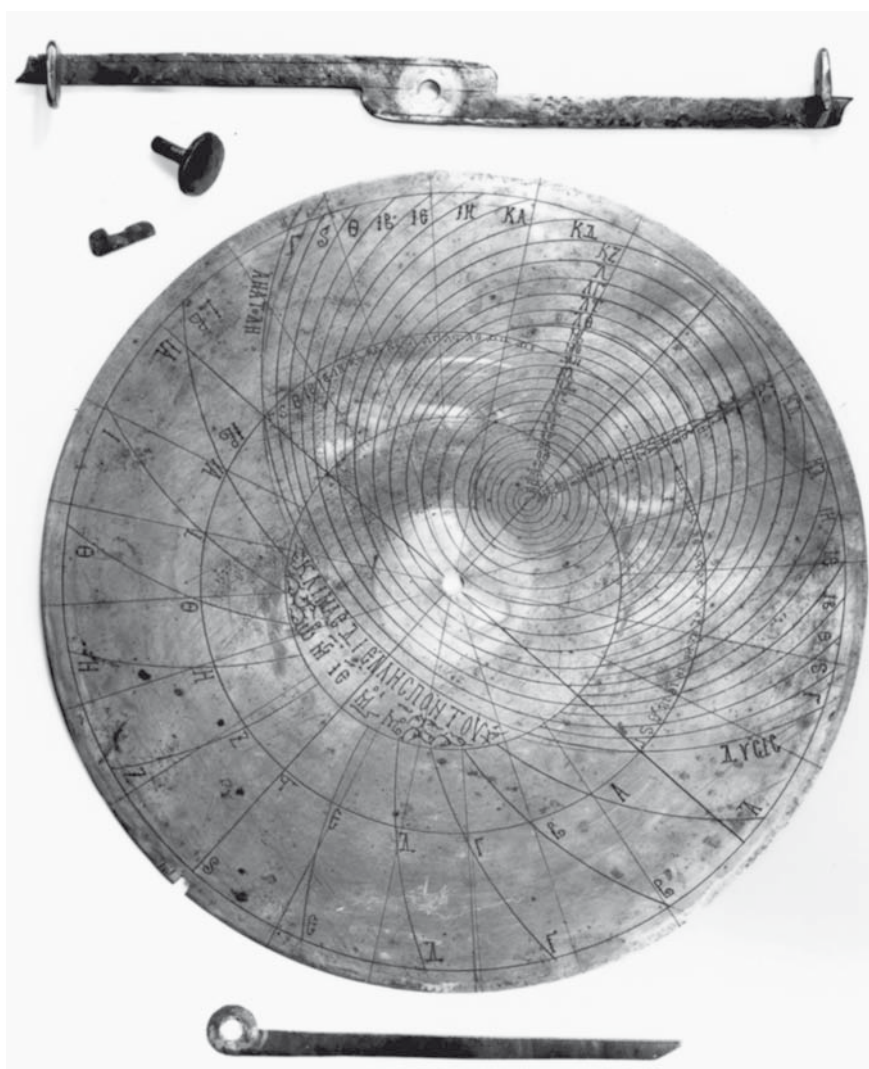
Fig. 3.1 The plate for Hellespont with latitude 40° in the 4th climate on the sole surviving Byzantine astrolabe, dated 1062 (#2). Note the higher density of altitude circles between the two solstitial circles for timekeeping by the sun and the radial markings for the equinoctial hours, both features rarely found on Islamic or European astrolabes. See also **Figs. XIIIa-4.1a-b**. [Courtesy of the Museo del'Età Cristiana, Brescia.]

we have noted, some early instruments in each of the four main traditions of interest here—early Greek, early Eastern Islamic, early Western Islamic, and early European—the seven climates were featured, the innovation of featuring individual latitudes and/or individual localities soon came to predominate on early Islamic instruments and we find it again on numerous other early European astrolabes (for example, #300 with 24°-60° and #558 with 16°-52°), doubtless as the result of Islamic influence augmented by European needs. And in at least the Islamic tradition, both Eastern and Western, the associated maximum length of daylight

is usually stated alongside the latitude, serving as a reminder of the origin of the association: see **Table 2**.[23] In one case (#117), the minimum values are also given. Occasionally the values of daylight do not correspond correctly to the latitudes—see #99, #117 and #122.[24] This is particular unfortunate on a single plate (#109), where C6 is incorrectly associated with 41°, although the markings are actually for 45°: see **Fig. 3.2**.
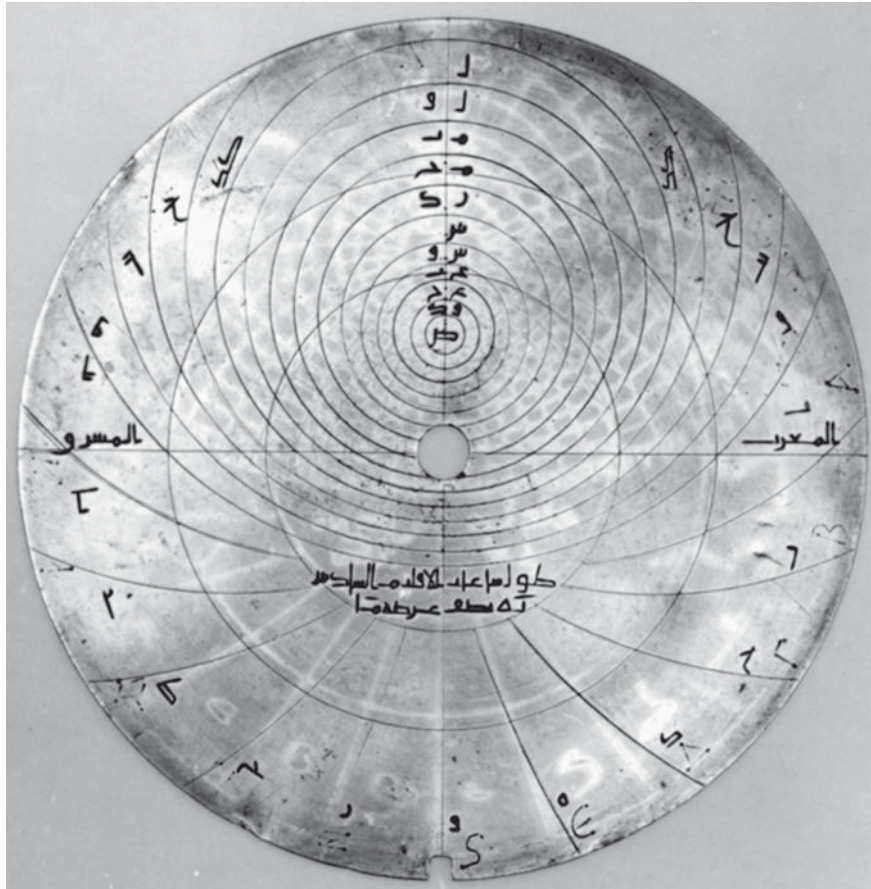
Fig. 3.2: Inside a late-13th-century Yemeni astrolabe (#109—see **XIVa**) we find a series of plates for various latitudes in the Yemen and the Hejaz, such as the one shown here on the left for 24°, serving Medina. In addition, however, there is a spurious early Islamic plate (9th or 10th century?), one side of which is shown here on the right. This has markings for latitude 45°, and the inscription reads: "The length of the hours in the 6th climate is 15 and a half and the latitude is 41° (*sic*)". Only the earliest Eastern Islamic astrolabes had plates for the climates. On this plate the seasonal hours are also labelled in capital Greek alphanumerical notation. See also **Fig. XIIIc-12.2**. [Courtesy of the Metropolitan Museum of Art, New York.]

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[23] It is a pleasure to thank my colleague Dr. Benno von Dalen for compiling this table. See n. 18 above.

[24] #99 has a plate for 39° associated with daylight 15 hours, whereas the correct value would be $14;48^{h}$. #117 has the wrong value for 35;30°. #122 has a plate for 31° with daylight $13;58^{h}$, which is correct for 30°. Note that on the plates for 30° and 42° on #101 the minutes of daylight have been suppressed (see also #99). In general the values are accurately computed, and there are two instances where daylight is given to seconds, perhaps suggesting that all values were originally calculated to this degree of precision: see the values for 21;40° on #118 and for 35;30° on #123, both of which reveal that it was wise not to give all values to seconds.

TABLE 2
The lengths of maximum daylight (D) as a function of terrestrial latitude (ϕ) for different values of the obliquity of the ecliptic (ε). Values are given for each 1° of ϕ, as well as for various significant latitude values given to minutes.

ϕ \ ε	24; 0°	23;51	23;35	23;33	23;31	23;29	ϕ \ ε	24; 0°	23;51	23;35	23;33	23;31	23;29
0°	12; 0^h	12; 0	12; 0	12; 0	12; 0	12; 0	33;10	14;15	14;14	14;13	14;12	14;12	14;12
1	12; 4	12; 4	12; 3	12; 3	12; 3	12; 3	33;25	14;17	14;16	14;14	14;14	14;13	14;13
2	12; 7	12; 7	12; 7	12; 7	12; 7	12; 7	33;30	14;17	14;16	14;14	14;14	14;14	14;14
3	12;11	12;11	12;10	12;10	12;10	12;10	34	14;20	14;19	14;17	14;17	14;17	14;16
4	12;14	12;14	12;14	12;14	12;14	12;14	34;20	14;22	14;21	14;19	14;19	14;18	14;18
5	12;18	12;18	12;18	12;17	12;17	12;17	34;30	14;23	14;22	14;20	14;19	14;19	14;19
6	12;21	12;21	12;21	12;21	12;21	12;21	35	14;25	14;24	14;22	14;22	14;22	14;22
7	12;25	12;25	12;25	12;25	12;25	12;24	35;30	14;28	14;27	14;25	14;25	14;25	14;24
8	12;29	12;28	12;28	12;28	12;28	12;28	36	14;31	14;30	14;28	14;28	14;27	14;27
9	12;32	12;32	12;32	12;32	12;32	12;32	36;30	14;34	14;33	14;31	14;31	14;30	14;30
10	12;36	12;36	12;35	12;35	12;35	12;35	37	14;37	14;36	14;34	14;33	14;33	14;33
10;30	12;38	12;38	12;37	12;37	12;37	12;37	37;30	14;40	14;39	14;37	14;36	14;36	14;36
11	12;40	12;39	12;39	12;39	12;39	12;39	38	14;43	14;42	14;40	14;39	14;39	14;39
12	12;43	12;43	12;43	12;43	12;42	12;42	38;20	14;45	14;44	14;42	14;41	14;41	14;41
12;25	12;45	12;45	12;44	12;44	12;44	12;44	38;30	14;46	14;45	14;43	14;42	14;42	14;42
13	12;47	12;47	12;46	12;46	12;46	12;46	39	14;49	14;48	14;46	14;45	14;45	14;45
13;37	12;50	12;49	12;49	12;48	12;48	12;48	39;30	14;52	14;51	14;49	14;48	14;48	14;48
14	12;51	12;51	12;50	12;50	12;50	12;50	39;40	14;53	14;52	14;50	14;50	14;49	14;49
14;30	12;53	12;53	12;52	12;52	12;52	12;52	39;52	14;55	14;53	14;51	14;51	14;50	14;50
15	12;55	12;54	12;54	12;54	12;54	12;53	40	14;55	14;54	14;52	14;52	14;51	14;51
16	12;59	12;58	12;58	12;57	12;57	12;57	40;30	14;59	14;57	14;55	14;55	14;55	14;54
16;30	13; 1	13; 0	12;59	12;59	12;59	12;59	41	15; 2	15; 1	14;58	14;58	14;58	14;58
17	13; 3	13; 2	13; 1	13; 1	13; 1	13; 1	41;15	15; 4	15; 2	15; 0	15; 0	14;59	14;59
17;30	13; 5	13; 4	13; 3	13; 3	13; 3	13; 3	41;30	15; 6	15; 4	15; 2	15; 1	15; 1	15; 1
18	13; 7	13; 6	13; 5	13; 5	13; 5	13; 5	42	15; 9	15; 8	15; 5	15; 5	15; 5	15; 4
19	13;11	13;10	13; 9	13; 9	13; 9	13; 9	42;30	15;13	15;11	15; 9	15; 8	15; 8	15; 8
20	13;15	13;14	13;13	13;13	13;13	13;13	43	15;16	15;15	15;12	15;12	15;12	15;11
21	13;19	13;18	13;17	13;17	13;17	13;17	43;30	15;20	15;18	15;16	15;15	15;15	15;15
21;30	13;21	13;20	13;19	13;19	13;19	13;19	44	15;24	15;22	15;19	15;19	15;19	15;18
21;40	13;22	13;21	13;20	13;20	13;20	13;20	45	15;32	15;30	15;27	15;27	15;26	15;26
22	13;23	13;22	13;21	13;21	13;21	13;21	45;30	15;36	15;34	15;31	15;31	15;30	15;30
23	13;27	13;27	13;25	13;25	13;25	13;25	46	15;40	15;38	15;35	15;35	15;34	15;34
24	13;31	13;31	13;30	13;30	13;29	13;29	47	15;48	15;46	15;43	15;43	15;43	15;42
25	13;36	13;35	13;34	13;34	13;34	13;34	47;30	15;53	15;51	15;48	15;47	15;47	15;46
26	13;40	13;40	13;38	13;38	13;38	13;38	48	15;57	15;55	15;52	15;52	15;51	15;51
27	13;45	13;44	13;43	13;43	13;42	13;42	48;30	16; 2	16; 0	15;57	15;56	15;56	15;55
28	13;50	13;49	13;47	13;47	13;47	13;47	49	16; 6	16; 5	16; 1	16; 1	16; 0	16; 0
28;20	13;51	13;50	13;49	13;49	13;49	13;48	49;30	16;11	16; 9	16; 6	16; 5	16; 5	16; 5
29	13;54	13;53	13;52	13;52	13;52	13;51	50	16;16	16;14	16;11	16;10	16;10	16; 9
29;36	13;57	13;56	13;55	13;55	13;54	13;54	51	16;27	16;25	16;21	16;21	16;20	16;20
29;55	13;59	13;58	13;56	13;56	13;56	13;56	52	16;38	16;36	16;32	16;31	16;31	16;30
30	13;59	13;58	13;57	13;57	13;56	13;56	53	16;50	16;47	16;43	16;43	16;42	16;42
31	14; 4	14; 3	14; 2	14; 1	14; 1	14; 1	54	17; 2	17; 0	16;55	16;55	16;54	16;54
31;30	14; 7	14; 6	14; 4	14; 4	14; 4	14; 4	55	17;16	17;13	17; 9	17; 8	17; 7	17; 7
32	14; 9	14; 8	14; 7	14; 6	14; 6	14; 6	56	17;30	17;28	17;23	17;22	17;21	17;21
32;25	14;11	14;10	14; 9	14; 9	14; 8	14; 8	57	17;46	17;43	17;38	17;37	17;37	17;36
32;30	14;12	14;11	14; 9	14; 9	14; 9	14; 9	58	18; 4	18;0	17;55	17;54	17;53	17;52
33	14;14	14;13	14;12	14;12	14;11	14;11	59	18;23	18;19	18;13	18;12	18;11	18;10
33;9	14;15	14;14	14;13	14;12	14;12	14;12	60	18;44	18;40	18;33	18;32	18;31	18;30

On two Western Islamic astrolabes, mixed information on localities and climates is presented: on #2572 we have Almeria at latitude 36;0° associated with C4, and on #3622 we find Hadramawt at latitude 12;25° associated with the beginning of C1 (daylight $12^{3}/_{4}$ hours). In both cases, no other localities are linked with climates in this way.

4 Universality achieved by a series of latitudes

The majority of surviving early Eastern Islamic astrolabes feature a selection of latitudes for specific localities rather than the middles of the climates. Some of these are clearly associable with the climates, others with their boundaries, and yet others with cities (usually not specifically mentioned) that were of importance: 33° for Baghdad, 34° for Samarra, 32° for Isfahan, 24° for Medina, 21° for Mecca, *etc*. It should be noted that Mecca and Medina are not always featured, so that we are not dealing with "essential travel-kit for pilgrims". Jerusalem, although commonly represented in Islamic geographical tables, is not found on any early Eastern Islamic astrolabes, but is found on three Western Islamic astrolabes (#3622, #117, #1139) and on some of the earliest European astrolabes (such as #162, from Catalonia *ca*. 1300, and #4560, from 14th-century Spain). Sometimes the selection was for each degree within certain limits, as is the case with #1026 (33°-36°). Only one early Islamic astrolabe (#99) associates localities with specific latitudes, namely, Mecca at 21° and Harran at 36°, and Fustat (Old Cairo) at the distinctive value 29;55°, apparently supposed to be the latitude of C3 (since daylight is rounded to 15 hours).[25] It is particularly appropriate that Harran be featured, since it was there in the 8th century, according to the 10th-century bibliographer Ibn al-Nadīm, that the Muslims first encountered the astrolabe.[26]

We should be very careful in assigning localities to latitudes on the basis of our own geographical knowledge. There is a gazetteer on a mater by Nasṭūlus (#1130, *ca*. 925),[27] unique amongst the surviving instruments before *ca*. 1100,[28] which can teach us a few lessons. Latitudes to the nearest degree are given for some 64 localities, Mecca and Medina at 21° and 24° and

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[25] This value occurs in a set of tables attributed to al-Khwārizmī (see n. 27 below) but not in his *Geography*; the corrupt reading 29;15° is recorded in a manuscript of the *Geography* of Suhrāb—see Kennedy & Kennedy, *Islamic Geographical Coordinates*, p. 111 (*sub* KHZ and SUH). Or was the original value 29;15° and the better value 29;55° derived by a misreading? In any case, the latter was still used by al-Marrākushī (article in EI_2) in Cairo *ca*. 1280. The late-10th-century astronomer Ibn Yūnus (article in *DSB*) complained that some people in his time thought that the latitude of Cairo-Fustat was 29;0° and that they were surprised that sundials based on this latitude did not work properly there. This value is associated with the astrologer Māshāʾallāh (Fustat, *ca*. 780—article in *DSB*)—see Kennedy & Kennedy, *Islamic Geographical Coordinates*, p. 111 (*sub* MSH YAQ). Ibn Yūnus seems to have been the first person to measure the latitude properly as 30;0°.

Note that the 10th-century astrolabist who made #99 (see **XIIIc-2**) labelled one of his plates for "*Miṣr*", meaning "Old Cairo", that is, Fustat. And it is Fustat which appears explicitly in the gazetteer of Nasṭūlus on #1030 (see **XIIIc-3b**, no. 46), datable *ca*. 925. The new city of al-Qāhira (Cairo) was founded in the year 969, but astrolabists in 11th-century al-Andalus continued to use the expression *Miṣr*, meaning *Miṣr al-Qāhira*, or Cairo-Fustat (see the article "Miṣr" in EI_2, especially pp. 146-147).

[26] See **XIIIc-0**.

[27] On the maker see now **XIIIc-3**.

[28] See n. 11 above.

the rest between 30° and 37° except for Tiflis at 41°, the purpose surely being to show which plates one should use in the various localities, but alas no plates survive for this instrument. The data are presented in **XIIIc-3b**, and most of the entries are derived from those of al-Khwārizmī, the most significant 9th-century geographer, who apparently took his data from a Ptolemaic world-map, modifying the longitudes as appropriate.[29] The data serve as a gentle reminder that we should not use modern latitudes to investigate medieval materials. Thus Nasṭūlus on his other surviving astrolabe (#3501) has a single plate for 33° and 36°. I would have thought this would have been intended for Baghdad (and perhaps Damascus) and Mosul (with or without Aleppo). However, whilst we are in luck with 33°, Nasṭūlus put Mosul at 35° and Aleppo at 34°. At 36° he has Massisa, Tarsus, Balad, Nisibin, Balis and Ardebil, but we do not need to choose between these because 36° is also the middle of C4 for the Ptolemaic value of the obliquity, used by Nasṭūlus for the lengths of daylight on this plate.

In the case of two 10th-century Eastern Islamic astrolabes (#100 and #111) we find horary quadrants for a fixed latitude on the back:[30] on both the markings are for latitude 33°, which can only be for Baghdad. The maker of the first instrument, Ḥāmid ibn ʿAlī al-Wāsiṭī, is known to have worked in Baghdad, but the maker of the second, the astronomer Ḥāmid ibn Khiḍr al-Khujandī, is otherwise not known to have worked outside Rayy (near modern Tehran).[31] On #4022, an unsigned, undated piece, surely 10th century, there is an unlabelled quarter-circle on the trigonometric grid on the back: this can be used to find, for any solar longitude, the equation of half daylight for latitude 33°, which associates the piece with Baghdad. On #122, made in 1102/03 by a maker bearing the epithet al-Iṣfahānī, there are three sets of markings in the upper right quadrant on the back: graphical representations of the solar altitudes at the *ẓuhr* and *ʿaṣr* prayers[32] as well as the length of twilight for latitude 32° (presumably Isfahan, though note that Nasṭūlus put it at 34°!),[33] and a *miḥrāb* indicating the azimuth of the qibla at Isfahan (actually stated): see **Fig. XIIIc-11**.[34] The curves for the prayers are described already by al-Bīrūnī (early

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[29] On al-Khwārizmī see the *DSB* article by Gerald Toomer. All studies relating to his *Geography* are reprinted in *Islamic Geography*, vols. XI and XII.

The values that are not based on al-Khwārizmī are of particular interest. Some can be shown to be based on variant readings of his entries, or on alternative entries in his tradition (Suhrāb and Ibn Yūnus). But most interesting of all are those values which seem to be derived from an early source for the monumental *Kitāb al-Aṭwāl wa-'l-ʿurūḍ*, an 11th- century Iranian production which was to be highly influential in Iran for several centuries—see especially King, *Mecca-Centred World-Maps*, pp. 42-43 and 156-161, and now **VIIc**. Since no author, location or secure date can be associated with this work, any scraps of information we can gather on it are welcome.

[30] See n. 10 above.

[31] On al-Wāsiṭī see Mayer, *Islamic Astrolabists*, p. 45, and on al-Khujandī the articles in EI_2 and *DSB* (also the confused remarks in Mayer, *op. cit.*, p. 45). On their instruments see now **XIIIc-8-9**.

[32] These are defined by shadow-lengths, more specifically by the increases of the shadow over its minimum at midday. See al-Bīrūnī, *Shadows*, Chapters 25-26 of Kennedy's translation, and the article "Mikat. Astronomical Aspects" [= astronomical timekeeping] in EI_2, and now **II** on the way the prayer-times were determined and **IV** on the origins of the definitions.

[33] On Islamic twilight determinations see, for example, the EI_2 articles "Mīḳāt" and "Shafaḳ", and numerous tables described in **II**.

[34] On the sacred direction in Islam see the article "Ḳibla. Astronomical aspects" in EI_2, and King, *Mecca-Centred World-Maps*, pp. 47-127, where a wide variety of instruments for determining the qibla is discussed. See also **VIIa-c**.

11th century) in his treatise on shadows.[35] There are no other early Eastern Islamic astrolabes with markings of religious significance.

5 All roads lead to Rome, but which Rome?

The majority of surviving early Western Islamic astrolabes (post-dating the earliest that have markings for the climates) have lists of localities in the Iberian Peninsula and the Maghrib as well as in the Islamic East. The idea, which, as noted above, was possibly Byzantine in origin, may have come to al-Andalus with a hypothetical late (Graeco-)Roman tradition of astrolabe-making, of which we seem to have one example, namely, #3042, from 10th-century Catalonia.[36] On this, one of the plates, for 41;30°, is marked "Roma et Francia", intended to serve the locale where the instrument was made (Francia here means Catalonia), and—I would maintain—the locale where this particular astrolabe tradition came from, namely, Rome. There are also markings for latitudes 36° (intended for Rhodes?, "Africa"?, C4?), 39° (Sicily?, Naples?, and/or Cordova?, C4/C5?) and 45° (Vienne?, Po Valley?, C6?); the rationale behind those for 47;30° defies satisfactory explanation for the time being.[37]

Amongst the geographical data on these early Western Islamic astrolabes we do indeed find mention of Rome (see **Fig. 7.1**), a city that one might think would have been of no consequence whatsoever for Muslims.[38] I would maintain that the inclusion of Rome provides another instance of the influence of this hypothetical (Graeco-)Roman tradition. No less interesting from a

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[35] al-Bīrūnī, *Shadows*, I, pp. 236-238 (translation), and II, pp. 147-148 (commentary). On al-Bīrūnī see Kennedy's splendid article in *DSB*.

[36] This provenance was proposed by Marcel Destombes, and is accepted by Paul Kunitzsch and Julio Samsó as well as by the present writer, if not yet by the "Paris school" (see **XIIIa-9**). Various other opinions are expressed in Stevens *et al*., eds., *Oldest Latin Astrolabe*. Julio Samsó, in his "*Roma et Francia* (= *Ifranja*)", discusses the meaning of Francia, which, as he shows, cannot be understood without reference to Islamic sources. Anscari Mundó, in his "Analyse paléographique de l'astrolabe 'carolingien'", discusses the distinctive forms of the letters in the engraving, which, as he shows, are all attested in other 10th-century Catalan inscriptions. In my contribution to that volume ("The Oldest European Astrolabe"), I compare numerous details on it with those on several dozen other Islamic and European pieces. Various aspects of it remain inexplicable, hence my postulation of a hypothetical Roman tradition from which various features—including the design of the rete, the plate for Rome and the calendrical scale on the back with Roman month-names—may be derived (on p. 384 of my article the section beginning "An astrolabe from *ca*. 1300 ... " should be preceded by the words: "Added in proof"). Islamic influence is apparent in the azimuth curves on the plates (first introduced in 9th-century Baghdad) and the alphanumerical notation used on the altitude scale and to represent the latitudes of the plates (which is based on the Western Islamic alphanumerical system, rather than, say, the Greek or Eastern Islamic ones).

[37] One possibility would be a leftover from Antiquity, namely, Heraclea Pontica on the Black Sea (Turkish Ereğli), which Ptolemy put at 41;50° (actually 41°17′) but which some early Muslim scholars put at 46;35° (close to C6/7) and 47;35° (possibly the result of a scribal error)—see Kennedy & Kennedy, *Islamic Geographical Coordinates*, pp. 138-139. Note that in the two 15th-century European lists published in North, *Horoscopes and History*, pp. 186-195, "Eraclia" is still at 46;35° and there is an awkward gap between 46;50° (Cologne!) and 48;0° (Paris).

[38] One would, however, be wrong, because Muslims were fascinated by Rome: see El-Munajjid, "Rome vue par les géographes musulmans", and the article " Rūmiya" by R. Traini in EI_2, mentioning the "ambiguous geographical representation" of Rome by the Muslims, which goes back to Constrantinople, and resulted from the influence of the Graeco-Byzantine and Syriac tradition. Also Western Islamic instrument-makers were not averse to using Arabicized forms of the Roman month-names on their calendar-scales—see Maier, "Romanische Monatsnamen", B.

historical point of view, and of importance for the later history of medieval astronomy, even Byzantine astronomy, was the unfortunate association of Byzantium with the 6th rather than, more appropriately, the 5th climate. As a result of this error, Constantinople is often given a latitude of 45° (as on #3650 and #116, as well as in most geographical tables[39]) rather than, say, 41°, which would be more reasonable.[40] There seem to me to be two possibilities:

(1) Either, there was a Roman tradition of astrolabe-making in which the plates were labelled for Rome, as well as, say, Sicily and Africa to the south,[41] and various points north. In this case, the 10th-century Catalan astrolabe (#3042) with one plate for Rome (and Catalonia) is the main witness to this tradition.

(2) Or, there was no such tradition, and the Rome called *Rūmiya al-kubrā* at *ca*. 41;30° on some Andalusī astrolabes (#2527—see also #121, but compare #123, where it is called simply *Rūma*) was actually originally intended to be Constantinople.[42] In other words, the fact that Constantinople was given two different latitudes by medieval astronomers may have led to one of these "Constantinoples" being interpreted as Rome by at least the maker of the Catalan astrolabe (#3042). And the *Rūmiya al-kubrā* on Andalusī astrolabes became Rome (as on #123) and *Qusṭanṭīniyya* remained Constantinople (as on #3650, #1216, and #4040).

6 Astronomical observations and mathematical calculations reflected in the geographical data

We find non-integral latitudes reflecting 9th-century observations, as in the case of 21;40° for Mecca (on #3650, #3622, *etc*.). This was the result obtained from measurements commissioned by the Abbasid Caliph al-Maʾmūn. And some latitudes are not attested in any known medieval geographical tables: for example, 39;52° for Toledo, *etc*. on #117, which, however, just happens to be the accurate value for Toledo, and one can assume that some very competent astronomer actually derived it by careful observations.[43]

In the case of 33;9° for Baghdad (on #121, rounded to 33;10° on #117 and #2527), I suspect that this value might have been derived by calculation as the boundary of C3/C4 using obliquity 24° (see **Table 1**).[44] Certainly it is attested in 9th- and 10th-century Eastern Islamic geographical

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[39] See Kennedy & Kennedy, *Islamic Geographical Coordinates*, pp. 93-94, and also North, *Horoscopes and History*, p. 193.

[40] King, "Astronomical Instruments between East and West", p. 169, and my remarks in "Byzantine Astronomy", pp. 117-118. My colleague Dr. Sonja Brentjes kindly drew my attention to the fact that this problem was noted by European scholars already in the 17th century—see Staphorst & Ray, eds., *Curious Travels*, II, p. 42-43.

[41] Note that some medieval European astrolabes feature precisely these two regions: for example, the 13th(?)-century Catalan piece #416—see already King & Maier, "London Catalan Astrolabe", pp. 694-695, n. 60.

[42] The very name *Rūmiya al-kubrā*, with the epithet *al-kubrā*, "the greater", applies in fact to Constantinople: see the article "Istanbul" by Halil Inalcik in EI_2, especially p. 224a.

[43] See now Chabás & Goldstein, *The Alfonsine Tables of Toledo*, pp. 145, 183, 211 and 302, for attestations of 39;54° in the 13th-century *Alphonsine Tables*. Compare North, *Horoscopes and History*, p. 192, with the two values 39;54° and 39;58° in a 15th-century source.

[44] The value 33;9° is used in a limited number of early-9th-century tables (MS Oxford Marsh 663), whereas the value 33;21°, derived by observations, seems to have been more popular (MS Escorial ár. 932). On the other

tables, having been used by al-Khwārizmī (*fl*. Baghdad *ca*. 825) and al-Battānī (*fl*. Raqqa *ca*. 910),[45] both of whose works were known in al-Andalus.[46]

With a value such as 38;30° for Cordova (on #3650, #116, *etc*. and in numerous geographical tables), better than Ptolemy's 38;50° but not as good as Theon's 38;5° (the accurate value is 37°53′),[47] we have no idea who first proposed it.[48] It was possibly derived as the latitude of C4/C5 using the Ptolemaic obliquity.

7 Universality achieved by intense engraving

Several early Western Islamic astrolabes contain a relatively large number of plates which display an impressive number of city-names alongside the latitudes, a veritable feat of engraving skills, even if some names had to be "hyphenated" and continued on the next line (most unusual in Arabic). See **Fig. 7.1** for an example. Mecca and Medina are now almost always included (#110 is an exception). Also there are invariably curves amongst those for the seasonal hours for the *ẓuhr* and the *ʿaṣr* prayers, as well as altitude circles (below or above the horizon) for determining daybreak and nightfall, that is, for the *fajr* and *ʿishāʾ* prayers. The latitudes occasionally begin with the equator (see below), and below and up to Mecca sometimes include such exotic places as Ghāna at 10;30° (on #116);[49] Ḥaḍramawt at 12;25° (on #3622); Sabaʾ (Sheba) at 17;30° (on #3650, *etc*.);[50] the capital of China at 18° (on #2572);[51] Kūkū (Gaw in Mali) at 21;40° (on #2527);[52] and al-Manṣūra "in China" (actually in Sind) at 23° (on #4040). The majority of localities lie between latitudes 30° (Cairo, *etc*.) and 45° (Constantinople, *etc*.), and whilst cities in the Maghrib and Muslim Spain feature prominently, the makers were not averse to including such far away places as Bukhara and Samarqand. In addition to Rome (see above), we note the following localities outside the Islamic commonwealth: Cyprus, which inspite of numerous attacks still remained part of the Byzantine Empire, on #117; and Sardinia, whose inhabitants fought constantly to keep the Muslims out, and perhaps Marseilles (?—no photos available, perhaps my reading was in error), albeit at latitude 38;30°, so probably an error for Messina,[53] both on #2527.

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hand, the value 33;0° was also rather popular (see elsewhere in MS Oxford Marsh 663 and also King, "al-Khwārizmī", p. 2).

[45] On al-Khwārizmī see n. 27 above. On al-Battānī see the *DSB* article by Willy Hartner.

[46] Indeed, by an accident of history, they were the only two out of several dozen early Islamic astronomical handbooks that were transmitted to the West.

[47] Kennedy & Kennedy, *Islamic Geographical Coordinates*, p. 95; and King, "Andalusī Sundials", p. 374.

[48] In the original version of this study I added an absurd note in proof" (pp. 16-17) about the origin of these Andalusī latitude values—see the notes at the beginning of this version.

[49] A town in the Nigerian Sudan now vanished—see the article "Ghāna" in EI_2.

[50] Destroyed long before the advent of Islam, but mentioned in the *Qurʾān*—see the article "Sabaʾ" by A. F. L. Beeston in EI_2.

[51] This is probably Guangzhou (Canton)—see the article "al-Ṣīn" [= China] in EI_2, and also Kennedy & Kennedy, *Islamic Geographical Coordinates*, pp. 91 (China, *etc*.) and 180 (Khanqu). Canton is actually at 22°8′, but various early sources give 18;0°, 18;15° or 18;30° for the "city" of China.

[52] Probably to be identified with Gao in Mali, whose name is written *K-w-k-w* or *K-w-k-h* (as on this astrolabe), sometimes put on the Nile, sometimes in Ghana, sometimes south of the equator. See Kennedy & Kennedy, *Islamic Geographical Coordinates*, pp. 191-192.

[53] Kennedy & Kennedy, *op. cit*., p. 218, gives for Marseilles only the Ptolemaic value 43;4°, an early Eastern
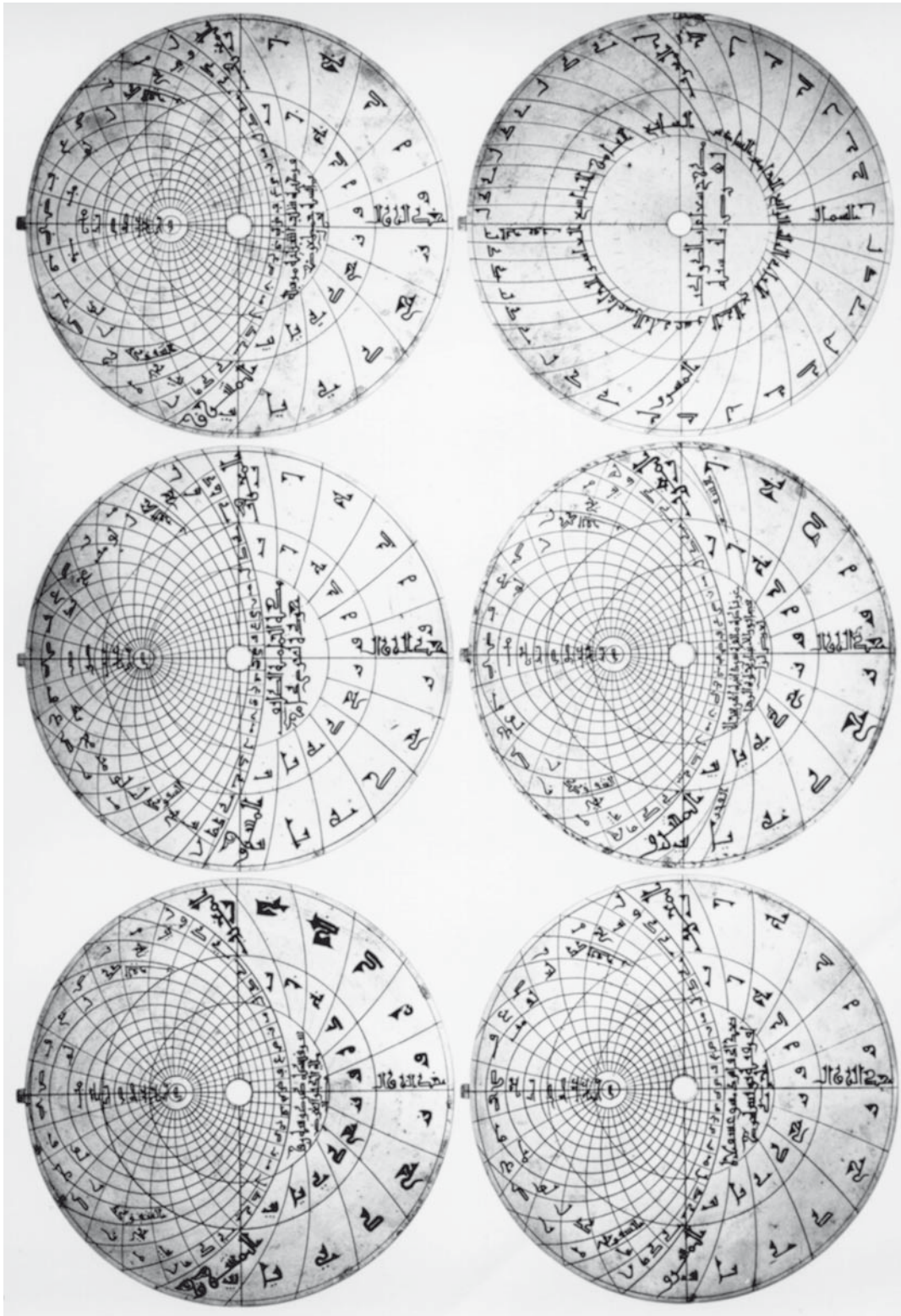
Fig. 7.1 Although the earliest Andalusī astrolabes had plates for the climates, by the 11th century Andalusī astrolabe-plates usually had a series of localities engraved by the side of each latitude. On the plate for latitude 43° (upper left) in the astrolabe of Muḥammad al-Ṣabbān dated 474 H [= 1081/82] (#2527), Saragossa, Tortosa and Rome are mentioned. The presence of a special plate for astrological purposes marked for Valencia (lower right), and another one for Saragossa, indicates that the instrument was made in one or other of those cities. [Courtesy of the Museum for the History of Science, Oxford.]

It is worthwhile to seek a source for these geographical data amongst the several early sets of Islamic geographical tables,[54] but this is an operation frought with difficulty, not least in cases where the latitudes are expressed to the nearest degree. Also, some localities are given different latitudes, even by the same maker: thus, for example, Saragossa can be found at 41;30°, 42° and even 43;30°[55] (#117, #3650, #116, #2527 and #1139).

We may anticipate that rarely-attested localities, distinctive latitude values, and errors of one sort or another[56] can provide the most clues. If we consider the unusual value 38;20° for Cordova on #117, we find that it is taken from al-Khwārizmī. So is the value 35;30° for Mosul, but not the 37;30° for Seville or 41;30° for Saragossa. Likewise, Tawiyus (possibly from Greek Takaphoris) occurs on #118 along with Qulzum at 28;20°. al-Khwārizmī and his heirs have 28;0°, but no other Islamic sources mention this locality. Also on #118 (as well as #4040), Tunis is given an absurd latitude of 33;0°, but this is precisely the value of al-Khwārizmī, rounded from that of Ptolemy. On #117, by the same maker, it is given the latitude 33;10°, but only because it is preceded by Baghdad, and the value here is simply rounded from al-Khwārizmī's 33;9°. On #2527 Homs has landed at 38;30°, which results from a scribal error for 33;30°, but al-Khwārizmī had 34;0°. On the same instrument (and on #1099) Anbar is at 37;30°, which results from a scribal error for 34;30°, given by Suhrāb in the tradition of al-Khwārizmī.

Most of the Andalusī place-names are not in al-Khwārizmī (or al-Battānī). We have already noted the value 39;52° for Toledo, which seems to be the result of careful observations. There is also a serious value for Burgos, namely, 42°, on #154, which is not attested in the textual sources. Whilst it would be unwise to associate the latitudes of a given plate with each of the localities mentioned on the same plate, it is clear that in the early 11th century someone did some serious thinking about the geography of al-Andalus and that we have here some evidence of this activity. Now the first independent geographical table from al-Andalus was prepared around the middle of the 11th century by Isḥāq ibn al-Ḥasan al-Zayyāt.[57] This included some 300 entries and whilst being related to Eastern Islamic sources it did feature a relatively large number of localities in the Islamic West. Although this accounts for the inclusion of various localities on astrolabe-plates, it does not always account for the latitudes accorded them. For example, al-Zayyāt has 38;10° for Cordova, 37° for Tunis and 43;0° for Rome, and 10;15° for Kuku, none of which values are found on the plates. In addition there are several localities featured on the

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Islamic value 43;0°, and 44;0° from the *Toledan Tables*. The value 38;30° for Messina is Ptolemaic: see *ibid*., p. 228, and also North, *Horoscopes and History*, p. 192.

[54] John North (*Horoscopes and History*, p. 186) has stated that the law of diminishing returns governs such undertakings, but this is, as the English say, a "cop-out". In fact, this is the sort of material on which doctoral candidates can be nurtured. On the other hand, I have refrained from organizing the Western Islamic data by place-name, which is also a cop-out.

[55] This latitude is confirmed by the corresponding length of daylight. The accurate value is 41°39′.

[56] The alphanumerical notation used for numbers in astronomical and geographical tables led to different classes of numerical distortions (such as 3 ↔ 8, 10 ↔ 50, *etc*.). See Irani, "Arabic Numeral Forms", on the notation, and King, *Mecca-Centred World-Maps*, pp. 161-163, on the consequences.

[57] On al-Zayyāt see Kennedy & Kennedy, *Islamic Geographical Coordinates*, p. xxxvii, and Comes, "Meridian of Water", on the later fate of his tradition in Egypt see King, *Mecca-Centred World-Maps*, pp. 80-84. There is a lot more to be said about al-Zayyāt and his table.

plates that are not in al-Zayyāt's list, such as Uclés and Calatrava. And sometimes when obscure places in the East appear, such as Siniz (near Ahwaz) at 30° (on #117 and #4040), it is not clear where the entry comes from, since both al-Khwārizmī and al-Zayyāt have it. On the other hand, we note that whilst Santarém (with actual latitude 39°14′) is at 42° on an early piece (#110), it is given al-Zayyāt's better value 40° on two later ones (#3622 and #2527).

On the plate for latitude 35;30° on #117 the more precise latitudes of seven localities are listed (see **Fig. 7.2** inserted after **Section 12**):

Mosul	35;30°	attested in al-Khwārizmī *et al*.
Rusafa	35;40°	attested in al-Battānī *et al*.
Manbij	35;30°	attested in al-Khwārizmī *et al*.
Mada'in	35;30°	Ptolemaic, not attested in the Islamic sources
Cyprus	35;10°	not attested
Sicily	35;30°	not attested
Ceuta	35;20°	standard Islamic value but not in al-Khwārizmī or al-Battānī

Of these values three are found in either al-Khwārizmī or al-Battānī, three others are not attested in the Islamic sources (though one is Ptolemaic), and one is standard Islamic (though not in al-Khwārizmī or al-Battānī).

In brief, the data on the Western Islamic astrolabes are a curious mixture of al-Khwārizmī (and hence ultimately Ptolemy) and al-Zayyāt, a few new observed values for cities in Muslim Spain, and various roundings and misreadings.

In 2004, I saw an early-18th-century Maghribi astrolabe (#4300) that had a series of plates for various latitudes, including the distinctive 33;40° for [Fez], first attested on the astrolabes of Abū Bakr ibn Yūsuf in Marrakesh in the early 13th century, as well as 21° for Mecca and 25° for Medina.[58] Other plates served Tunis 37°, Tripoli 36°, Alexandria 31°, Cairo 30°, and 41°, surely for *Constantinople*. Nothing remarkable about this. However, an inscription on the mater records the longitudes of *Constantine* (Algeria), Kairouan, Tunis, Tripoli, Gabes, Medina, Mecca, Cairo, Alexandria and Fez. The maker was clearly concerned to indicate the coordinates of a series of localities between Fez and the Holy Cities of Mecca and Medina. He came unstuck with the latitude of *Qusunṭīniyya*, making a plate for *Qusṭanṭiniyya* instead; otherwise, his astrolabe represents an attempt to produce an instrument for a Maghibi pilgrim to take on the *ḥajj*.

8 Universality by horizons alone

The plate of horizons, with four sets of markings in each quadrant, the ensemble serving for a complete range of latitudes, was apparently introduced by Ḥabash al-Ḥāsib in the mid 9th

[58] Described and illustrated in *Christie's London 30.06.2004 Catalogue*, pp. 26-27 (lot 149). See also the text to n. 182 in **XV**.

century.[59] We first find such a plate on the astrolabe of al-Khujandī (#111), with underlying obliquity stated as 23;33°, the first value found by the astronomers of al-Maʾmūn (although the daylight values on the plates are based on 23;51°). Likewise an Andalusī set of plates (#4040) includes one for the horizons also indicating an obliquity of 23;33°.

9 Astrological overtones

Astrological information is found already occasionally on 10th-century Eastern Islamic astrolabes, such as that of al-Khujandī (#111).[60] Furthermore, a minority of surviving early Islamic Eastern and Western astrolabes have one or two additional plates marked for astrological purposes, presumably at least for the place where the instrument was made. Thus the same instrument (#111) has markings for the equalization of the houses and the casting of the rays[61] for an unspecified latitude, actually 33°, confirming the association with Baghdad (see **4** above). The astrolabe of Ibrāhīm ibn al-Sahlī (#121) has the same for 38;30° and 41;30°, which must be for Cordova and Saragossa, as we see from the indications on the corresponding standard plates. That of Muḥammad al-Ṣabbān (#2527) has similar markings for Valencia and Saragossa, and an unsigned set of plates (#4040) the same for latitude 35°, apparently indicating that the maker favoured (or worked in) Ceuta or Tangiers.

10 From the equator to the Arctic circle and beyond

Markings for latitudes 0° and 90° first appear on the astrolabe of al-Khujandī (#111), serving pedagogic purposes and also satisfying intellectual curiosity: the associated lengths of daylight are stated as 12 hours and 6 months, respectively (see **Fig. 10.1**). On another Eastern Islamic astrolabe (#122) the markings are shown on the two halves of a single plate. Markings for latitude 0°, the equator, then appear on Western Islamic astrolabes (#3650, *etc*.), sometimes associated with Ceylon and the mythical islands of al-Yāqūt and al-Jawhar.[62] An astrolabic plate for the latitude of the Arctic circle has the nice property that the horizon corresponds precisely to the ecliptic on the rete. Thus, the astrolabic markings on the plate correspond to an ecliptic coordinate system, and they can therefore be used for converting ecliptic and equatorial coordinates, the latter represented—more or less—on the rete and surrounding scale. We find such a plate for the first time on the astrolabe of al-Khujandī (#111): see **Fig. 10.2**. Here the latitude is stated as 66;27°, implying an obliquity of 23;33°, the first value obtained by al-

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[59] Morley, "Astrolabe of Shāh Ḥusayn", p. 7, n. 12 (for Morley's Hanash read Ḥabash).

[60] The similar markings on #3 were added later. This information, straight out of Ptolemy's *Tetrabiblos*, is usually presented in the form of scales giving the limits and their lords, the faces, and the lords of day and night and the companion for each zodiacal sign. See Hartner, "Astrolabe", A, pp. 304-307 of the reprint, and now **XIIIc-9**, *etc*.

[61] See the article "Tasyīr" by Oskar Schirmer in EI_2, and North, *Horoscopes and History*, pp. 56-69.

[62] These were products of an uncontrollable desire to fill the gaps produced by the Indian Ocean in the sacred geography of a world centred on Mecca—see King, *The Sacred Geography of Islam* (forthcoming), summarized in the article "Makka. As centre of the world", in EI_2.

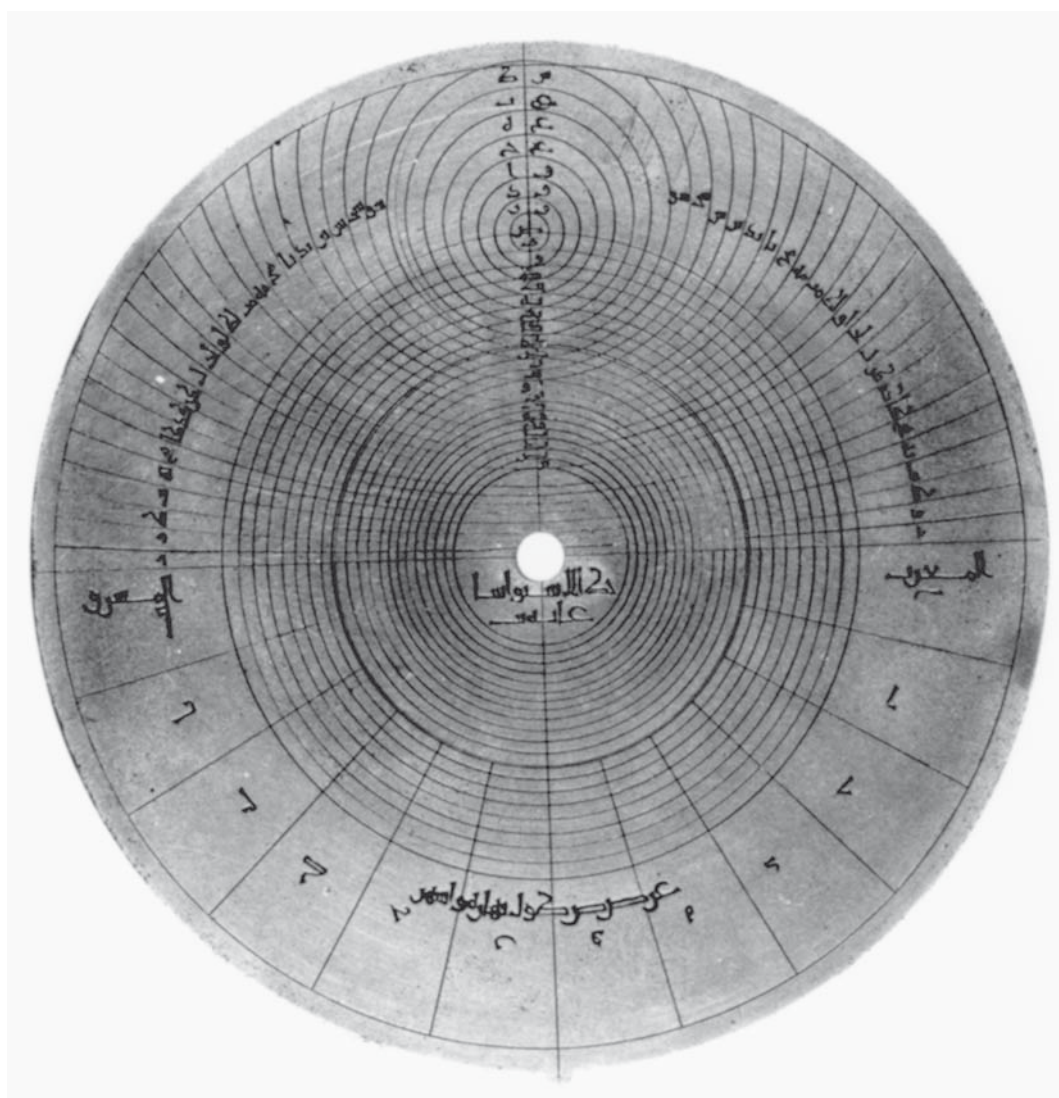
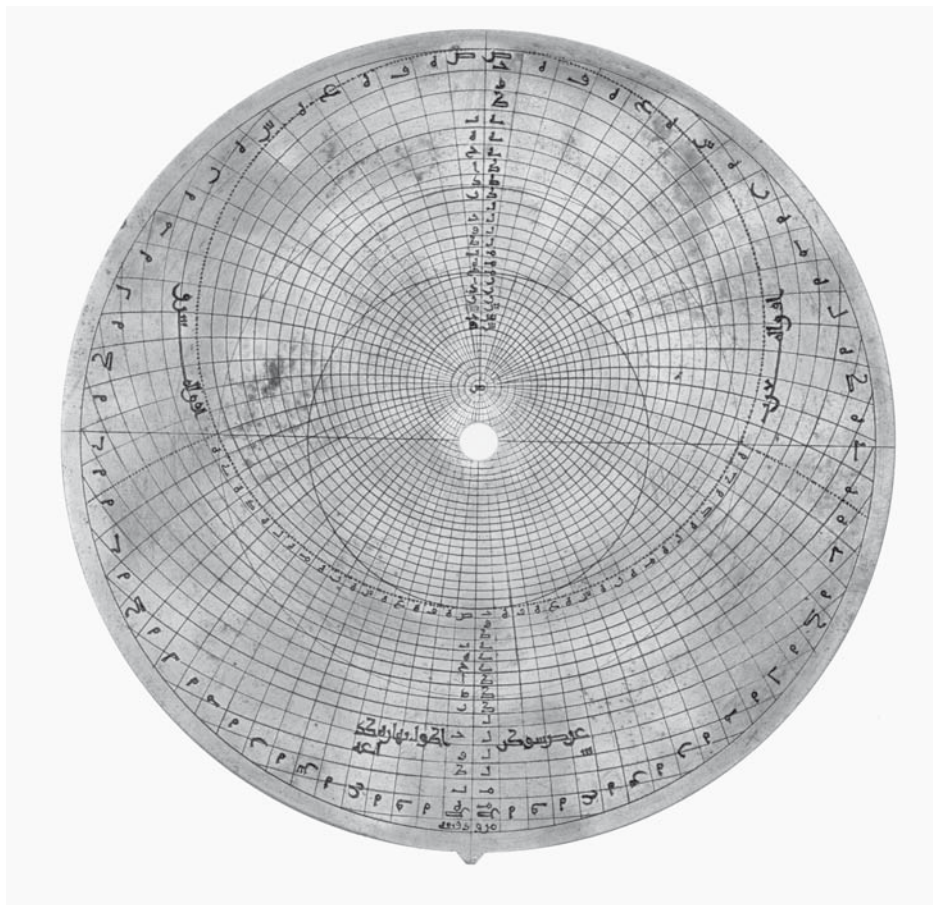
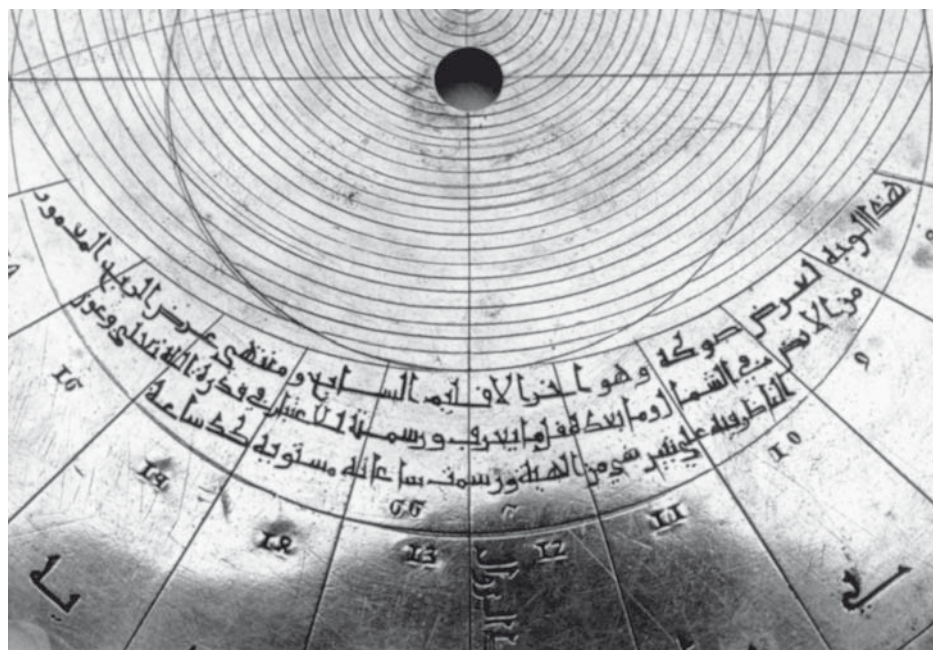



Fig. 10.1: The plate in the splendid astrolabe of the astronomer al-Khujandī, made in Baghdad in 374 H [= 984/85] (#111), that serves latitudes 0° (upper half) and 90° (lower half). [Private collection, photo courtesy of the owner.]

Maʾmūn's astronomers. On an astrolabe made in Cordova in the 11th century (#3622) the markings are associated with latitude 66;25°, underlying which is the second value obtained by these men, 23;35°, which was also accepted by al-Battānī. This, by the way, is the only one of the instruments discussed here in which there is any reference to the Creator as the force behind the subtleties of mathematical geography—see **Fig. 10.3** and the translation at the beginning of this study. On the instruments of the Andalusī Muḥammad ibn al-Ṣaffār (#3650 and #116) the latitude 66° is stated, implying an approximation of the Ptolemaic value. On the latter we also find markings for latitude 72°, which can only have served pedagogic purposes:

10.2

10.3

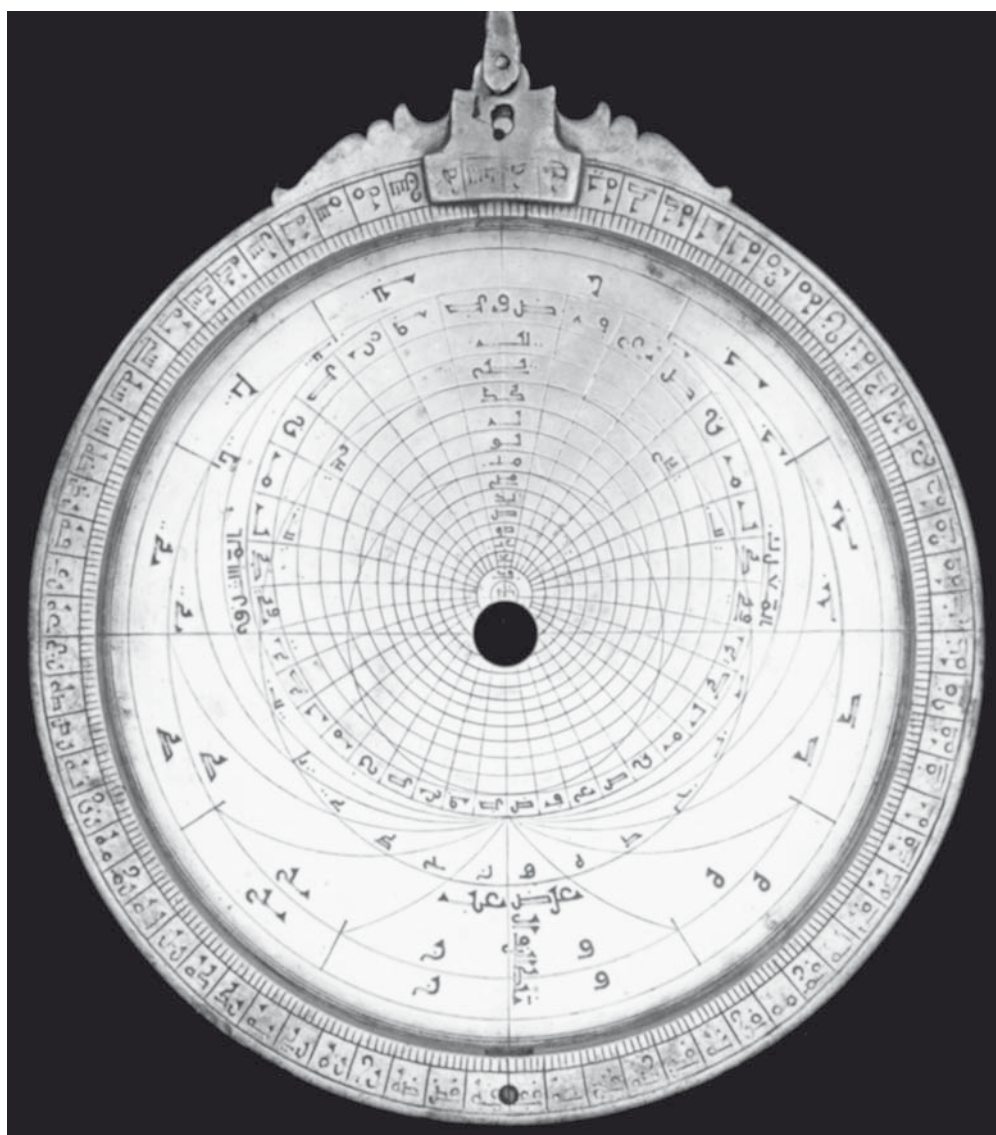



Fig. 10.4: Astrolabic markings for latitude 72° on the mater of an astrolabe by Muḥammad ibn al-Ṣaffār and dated 1029/30 (#116). Such markings, like those for latitudes 0° and 90°, could only serve pedagogic purposes. [Courtesy of the Westdeutsche Bibliothek, Marburg; object now in The Deutsche Staatsbibliothek, Berlin.]

←
Fig. 10.2: al-Khujandī's plate for latitude 66;27°, the earliest one of its kind. The underlying value of the obliquity is 23;33°, found by observation in Baghdad *ca*. 825. For the lengths of daylight on the plates of his astrolabe, al-Khujandī used the long-outdated Ptolemaic obliquity, 23;51°. This is curious not least because he is famed in the history of astronomy for his measurement of the obliquity as 23;32;21°, conducted in 994 (see **XIIIc-9**). [Private collection, photo courtesy of the owner.]
Fig. 10.3: The unusual inscription on the markings for latitude 66;25° on the mater of an unsigned astrolabe made in Cordova in 1054/55 (#3622), translated at the beginning of this study. [Photo by the author, courtesy of the Jagiellonian Museum, Cracow.]

see **Fig. 10.4**.[63] The corresponding markings on another Western Islamic piece (#121) serve 66;30° and 72°.

11 A Ptolemaic surprise

Of particular historical interest is the appearance amongst the plates of an 11th-century Western Islamic astrolabe (#4040) of a plate for 16;30° **south** of the equator ("behind the equator in the south"), the value for "Anti-Meroë" in Ptolemy's *Geography* and the lower limit of his world-map projections.[64] The existence of this plate is important evidence firstly that some knowledge of Ptolemy's *Geography* was available in al-Andalus at the time of construction; and secondly that plates for southern latitudes were known in al-Andalus in the 11th century. Perhaps it was from al-Andalus that the idea of representing southern rather than northern latitudes on the astronomical markings for astrolabic clocks came to medieval Europe.[65] In any case, this plate serves as a reminder that astrolabe plates were not necessarily constructed so that travellers could use them.

12 Concluding remarks

We have seen how the climates of Antiquity influenced the geography of early Islamic instruments. Furthermore, we have seen that the geographical data on early Islamic astrolabes from the East and the West were different in format and in spirit, if not also in intended application.[66] The large number of plates was not intended for practical purposes but to make the instrument universal.[67] The wide variety of information presented attests to an acute geographical awareness on the part of the Muslim instrument-makers, not always free from the limitations of blind traditionalism. They were also aware that the astrolabe is a model of the whole world—heavens and earth—that one can hold in one's hands. They made sure they did not neglect the terrestrial part of the instruments, namely, the plates, just as they rose to the challenge—in both scientific and artistic terms—of representing the fixed stars and sometimes even constellations on the celestial part, the rete. It is only when we have a clear idea of this that we can begin to understand what happened in the case of early European astrolabes,[68] which is far more complicated and not occasionally pathetic.

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[63] Or was it perhaps originally thought of as the "end" of the ocean surrounding the earth? See Kennedy & Kennedy, *Islamic Geographical Coordinates*, p. 248, where 71° is cited as the latitude of this extremity in a 15th-century source.

[64] Neugebauer, *ESA*, pp. 220-224, and *idem*, *HAMA*, II, pp. 934-940.

[65] On early European astronomical clocks, see North, "Monasticism and the First Mechanical Clocks".

[66] We have noted that only on one relatively late Eastern Islamic astrolabe (#122) are there any markings for the prayer-times and the qibla, and that markings for the prayer-times were standard on Western Islamic astrolabes. But mind the gap: the Eastern instruments are mainly 10th century, and the Western ones mainly 11th century.

[67] See n. 12 above.

[68] For the significance and potential of this kind of information see already, for example, King & Maier, "London Catalan Astrolabe", pp. 690-696 on #162 (where a latitude on a plate, probably derived by calculation, corresponds to the area of the dialect of medieval Catalan used for some star-names); King, "Picard Astrolabe",
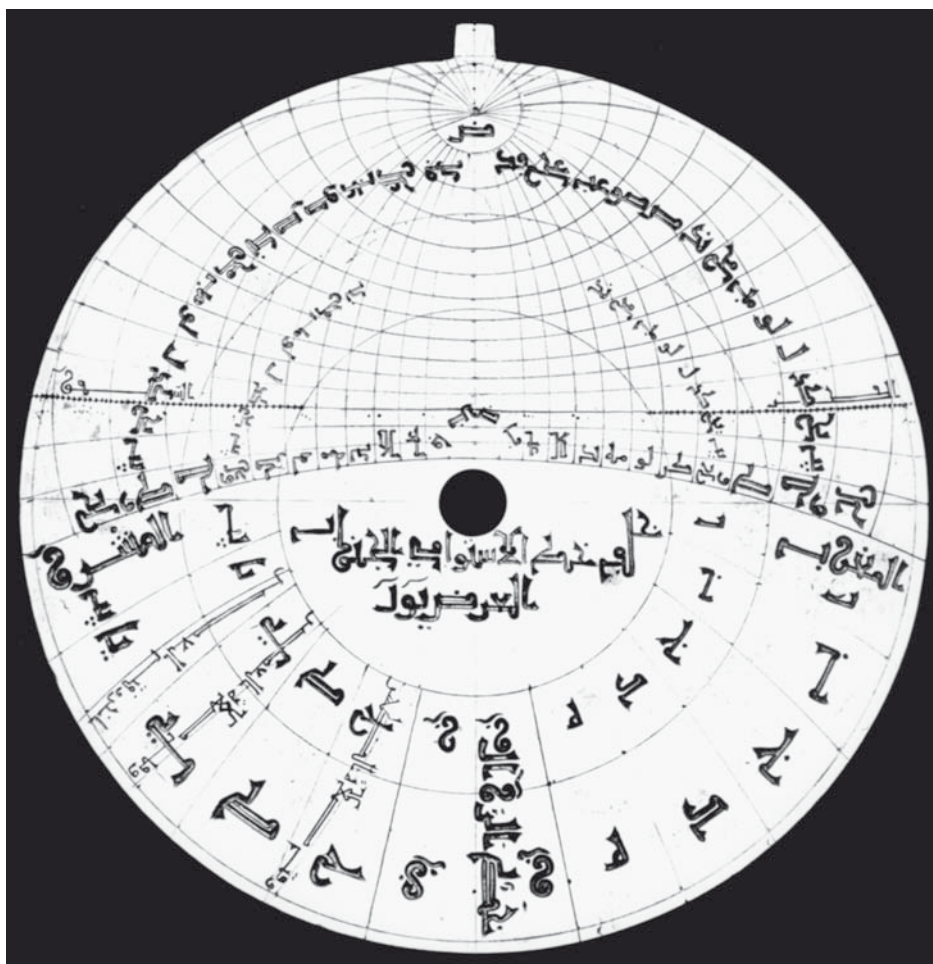
Fig. 11.1: The plate for latitude 16;30° **south** of the equator amidst a set of plates from an 11th-century Andalusī astrolabe (#4040). Quite unique in medieval instrumentation, this plate corresponds to the lower limit of Ptolemy's world-maps. Its existence raises a host of questions about the influence of Ptolemy's *Geography* in early Islamic science and about the Islamic background to medieval European astronomical clocks. [Private collection, photo courtesy of the owner.]

A nice example is #191, illustrated by Gunther.[69] This a composite piece comprising a 14th(?)-century Northern Italian mater, fitted with a rete copied from or modified from an Western Islamic one, and containing two sets of plates, one Northern Spanish for integral latitudes 41° and 42°

A, pp. 52 and 57, and *The Ciphers of the Monks*, pp. 138-141, on #202 (where a latitude on a plate with special markings corresponds to the area of the Picard dialect of medieval French used for the month-names); King & Turner, "Regiomontanus' Astrolabe", p. 186, on #640 (where a range of latitudes on a 15th-century astrolabe deemed suspect corresponds to that attributed to its maker by a 16th-century source); and Stautz, "Astrolab aus dem Jahr 1420", pp. 151-153, on #4523 (where the Northern Italian maker labelled his plates for latitudes 32°, 37°, 40°, 43°, 44°, 45° and 48°, but deviously constructed all of the markings for 45° (C6), that is, the Valley of the Po, where he felt most comfortable). Other examples are in n. 176 to **XV**.

[69] #191: see Gunther, *Astrolabes*, II, pp. 340-341 (no. 191), esp. pl. LXVIII.
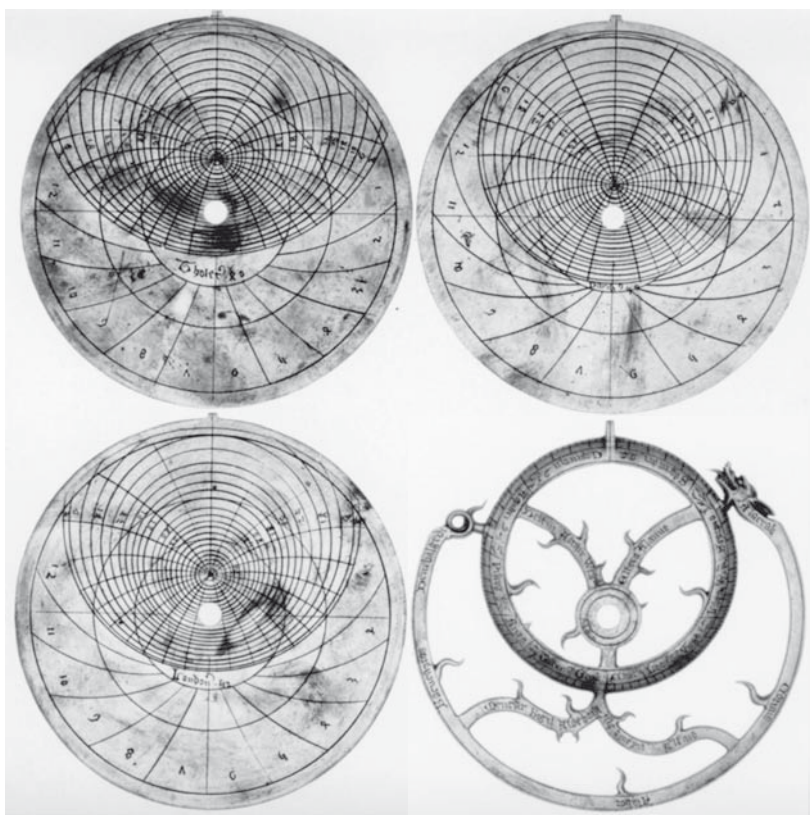
Fig. 12.1: The plates in this Chaucer-type English astrolabe (#299), with a Y-shaped frame on the rete, serve 40° Toledo, 42° Rome, 49° Cologne, 52° London, 57° Berwick, and 59° for Paris! Using the plates would be made difficult by the incorrect numbering of the altitude circles. [Courtesy of the Museum of the History of Science, Oxford.]
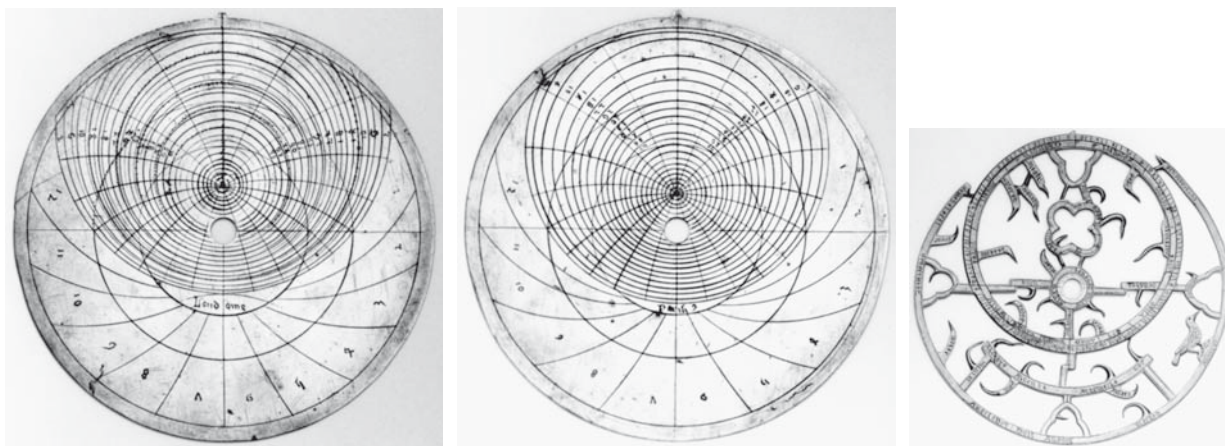
Fig. 12.2: Two plates of another English astrolabe (#4518), this one with quatrefoil decoration on the rete, have London in the low 50°s and Paris some 10° further north. This time, the construction of the altitude circles is a disaster, as well as their numbering. The other plates are for Rome, Cologne, York and Berwick. [Private collection; photos courtesy of the owner.]

(marked "Cesar Augusta" for Saragossa), 45° and 50°, as well as 57° and 58°, and the other Northern French for latitudes 45° and 48° (marked "Parisius"). Now why would a Spanish astrolabist make a plate for 57° and 58°? Part of the answer is in the *Toledan Tables*, where the Island of Thule is reduced from Ptolemy's 63° to 58;10°.[70] So why not make a plate for Thule? In fact, such a plate would have been about as useful to medieval European astronomers as ones for Kuku and Sheba would have been to their medieval Muslim counterparts. But it is still nice to have plates for such localities.

We might also mention two English astrolabe-makers, responsible for #299 and #4518, who lost control of their subject altogether when they put Paris at *ca*. 60°: see **Figs. 12.1-2**.[71]

But now it really is time to stop ... .
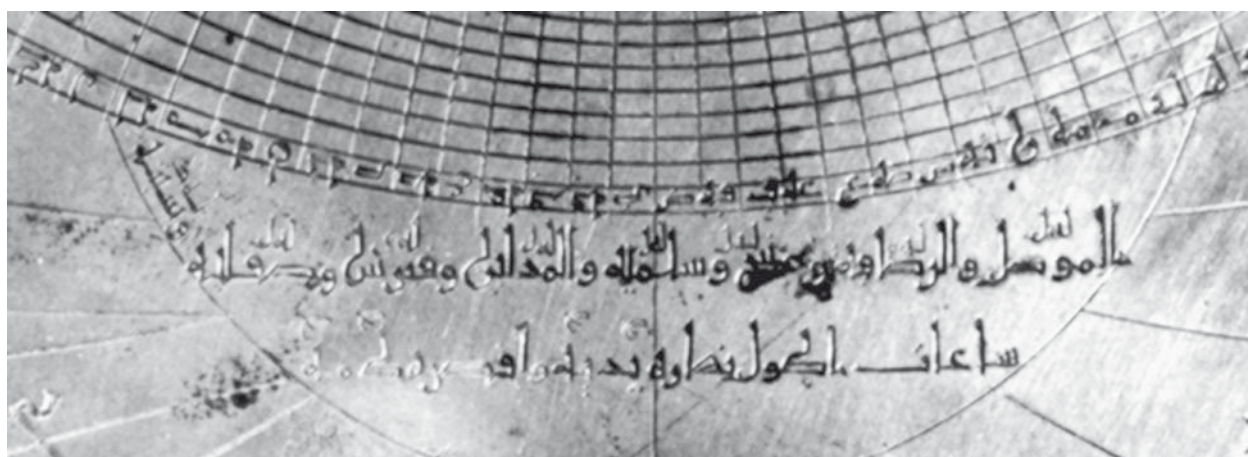
Fig. 7.2 (inserted in proof): The additional latitude values for certain cities inserted on the markings for latitude 35;30° on the astrolabe of Ibrāhīm ibn Saʿīd al-Sahlī (#117). [Courtesy of the Museo Arqueológico, Madrid.]

[70] See also North, *Horoscopes and History*, p. 195.

[71] #299: see Gunther, *Astrolabes*, II, pp. 475-476 (no. 299).

#4158: unpublished, though see *Brussels SG 1984 Exhibition Catalogue*, p. 37 (no. 7); and King, *Ciphers of the Monks*, pp. 305 and 308.

APPENDIX A: GEOGRAPHICAL DATA ON EARLY ASTROLABES (TO *CA*. 1100)

Key:

- Section in **XVIII**—Checklist number in **Appendix 3**—Present location (abbreviations are in **XVIII**)
- Maker if named (b. = ibn, Ibr. = Ibrāhīm, M. = Muḥammad)—Location of manufacture, if stated or ascertainlable—Date, if given (usually converted from Hijra date), otherwise estimated
- Density of altitude (H) and azimuth circles (A), above the horizon (A+) or below (A-)
- Obliquity underlying values of the length of longest daylight (only for Islamic astrolabes)

The main data gives the climates or latitudes featured on the plates, with lengths of maximum daylight and names of localities. Where daylight values are given, the errors in the minutes are shown in square brackets.

(a) Byzantine astrolabes

1.1.1—#2—Brescia MEC
Sergius the Persian, [Constantinople?], 1062
H/6°
-

36°	C4	Rhodes
40	C5	Hellespont
41	C5	Byzantium

1.1.2—#4509 – PC
unsigned, provenance?, undated (single plate)
H/2°
-

[43°]

(b) Eastern Islamic astrolabes

1.2.1—#3702—Baghdad AM
Reworked late 8th? C astrolabe, no original signature, [Harran? / Baghdad?]
H/6°
23;51°

C1	16°
C2	24
C3	30
C4	36
C5	41
C6	45
C7	48

1.2.2a—#1026—Oxford MHS
Khafīf, [Baghdad], undated
H/6°
23;51°

33° $14;13^{h}$ [0]
34 14;18 [-1]
35 14;22 [-2]
36 14;30 [0]

1.2.2c—#4030—Florence UG (illustration)
Khafīf, [Baghdad], undated
H/6°
23;51°

30 14 [+2]

no more information available (there were originally 3 plates)

1.2.3—#99—Paris BNF
Aḥmad b. Khalaf, [Baghdad], undated
H/6°, some A+/10°
23;51° (see below)

21°	Mecca	13;18	[0]
24	-	13;30	[-1]
29;55	*Miṣr**	14	[+2]
31	-	14; 6	[+3]
34	-	-	
36	-	-	
37	Harran	14;36	[0]
39	-	15	[!]

* here meaning Fustat – see the later Andalusī sources listed below where *Miṣr* means Cairo-Fustat

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1.2.4a—#3501—Kuwait DAI
Nasṭūlus, [Baghdad], 315 H
H/6°
23;51°

33° 14;13 [0]
36 14;30 [0]

1.2.5—#1179 – PLU < Berlin PC
M. b. Shaddād, undated
markings ?
?24°? or ?23;51°?

11° ?
21 13;19 [0/+1]

1.2.6—#4180—Rockford TM
al-Muḥsin b. M., undated
H/6°
23;51°.

24° ? -
31 14;3 [0]

1.2.7—#101—Florence MSS
Unsigned, undated
H/6°
23;51°

30° 14 [+2]
33 14;13 [0]
36 14;30 [0]
42 15 [-8]

1.2.8—#4022—London SM
Unsigned, undated
H/6° (A+/10° are later additions)
23;51°

24° 13;30 [-1]
28 13;47 [-2]
31 14; 4 [+1]
36 14;30 [0]
39 14;48 [0]

There was probably also a plate for 33°

1.2.10—#111—PC
al-Khujandī, [Baghdad?], 374 H
H/3°, some A+/5°, some A-/5°
23;51° (and 23;33° for plate serving 66;27°)

21°	13;18	[0]
27	13;44	[0]
30	13;58	[0]
33	14;13	[0]
36	14;30	[0]
39	14;48	[0
42	15; 7	[-1]
66;27	24	[0]
0°/90°	12h/6m	[0]

Rays for 33°, horizons

1.2.11—#3—Oxford MHS

The sons of Ibr. al-Iṣfahānī, [Isfahan], 374 H

H/6°, one with A-/10°

23;51°

30°	13;58	[0]
32	14; 8	[0]
33	14;13	[0]
36	14;30	[0]
37	14;36	[0]

some markings for twilight

1.2.12—#122—Florence MSS

M. al-Iṣfahānī, [Isfahan], 496 H

H/6°, some A-/10°

23;51°

24°	13;31	[0]
30	13;56	[-2]
31	13;58	[-5]
32	14; 8	[0]
33	14;13	[0]
36	14;30	[0]
0°/90°	-	-

Note: The daylight for 31° is accurate for 30°.

1.2.13—#4021—Copenhagen DS

Unsigned, undated

H/3° (ogival)

23;51°

36°	14;30	[0]
42°	15; 7	[-1]

1.2.14—#4020—London PC

Damaged, almost beyond recognition

markings ?

n.a.

36°

1.2.15b—#109 = #3549—New York MMA

Unsigned, undated

H/6°

23;51° or 24°

C6 = 41°	15 1/2^h
C7 = 48	16

There is a problem with these markings. The latitude of C6 is closer to 45°, which underlies the markings. The latitude of the seventh climate rounds to 48° only for obliquity 24°; for lower values of the obliquity it rounds to 49°.

1.2.14e—#1026—Oxford MHS

Unsigned, undated

H/6°

23;51°? or 23;33°/23;35°?

36°	14;28	[-2/0]
41	15; 0	[-1/+2]

(c) Western Islamic astrolabes

Key (in addition to that given above):
Curves for prayers indicated by z = *ẓuhr*, a = *ʿaṣr*, b = end of *ʿaṣr*
Curves for twilight indicated by t+ (above horizon) or t- (below it)

1.3.1—#4024—illustrated in MS Paris BNF 7412
Khalaf b. al-Muʿādh, undated (10th C)
H/6°
23;51°

C1	13^h	16;27°	[0]
C2	13 1/2	23;16	should be 23;49
C3	[14]	30;22	[+1]
C4	14 1/2	36; 6	should be 36;1
C5	15	40;56	[+3]
C6	15 1/2	45; 1	[0]
C7	16	48;32	[+1]

1.3.2—#110 = #135—London BM
Unsigned, undated
H/6° and A+/10°, some z, a, t+
-

30°	*Miṣr* (Cairo-Fustat), Kirman, Siraf
42	Almería, Harran, Samarqand, Tarsus
38;30	Cordova, Tudmir (Murcia), Ibiza
42	Toledo, Valencia, Denia, Badajoz
42	Saragossa, Medinaceli, Santarém

1.3.3a—#3650—Edinburgh RSM
M. b. al-Ṣaffār, Cordova, 417 H
H/6° and A+/10°

On the plate for 17;30° (the only one I have seen) there are curves for the *ẓuhr* and the beginning and end of the *ʿaṣr*, and the altitude circle at 18° is marked for twilight.
23;51°

0°	12	[0]	Equator, the Island of Ceylon, the Island of al-Yaqut and al-Jawhar
14;30	12;52	[-1]	Sanaa
17;30	13; 4	[0]	Sheba
21;40	13;22	[+1]	Mecca
25	13;35	[0]	Medina
28	13;49	[0]	Qulzum
30	13;59	[+1]	*Miṣr* (Cairo-Fustat)
32	14; 8	[0]	Kairouan
34;20	14;20	[-1]	Samarra
36	14;30	[0]	Tangiers
38;30	14;45	[0]	Cordova
40	14;54	[0]	Toledo
42	15; 8	[0]	Saragossa
45	15;30	[0]	Constantinople
66°	-	-	-

1.3.3b—#116—Marburg Berlin SBOA
M. b. al-Ṣaffār, Toledo, 420 H
H/6° and A+/10°, z, a, b, some t
23;51°

[0°]	[12; 0]	[0]	The Island of Ceylon, the Island of al-Yaqut
10;30	12;38	[0]	Ghana
14;30	12;52	[-1]	Sanaa
17;30	13; 4	[0]	Sheba
21;40	13;20	[-1]	Mecca
25	13;35	[0]	Medina
28	13;49	[0]	Qulzum
30	13;58	[0]	*Miṣr* (Cairo-Fustat)
32	14; 8	[0]	Kairouan
34;20	14;20	[-1]	Samarra
36;30	14;33	[0]	Samarqand
38;30	14;45	[0]	Cordova
40	14;54	[0]	Toledo
43;30	15;18	[0]	Saragossa
45	15;30	[0]	Constantinople
66/72	-	-	-

Rays for 38;30° and 42°

1.3.3c—#4025—Palermo MN
[M. b. al-Ṣaffār], undated

H/6° and A+/10°, z, a, b
40° Toledo
H/5° and no A
[42;30°] -

1.3.4—#3622—Cracow JUM
Unsigned, Cordova, 446 H
H/3° and A/5°, z, a, t-
23;51°

12;25°	12;45	[0]	Hadramawt, beginning of C1
21;40	13;21	[0]	Mecca
24	13;30	[-1]	Medina
27	13;44	[0]	Hejaz
30	13;53*	[-5]	*Miṣr* (Cairo-Fustat)
32	14; 8	[0]	Jerusalem, Kairouan
36;30	14;30	[-3]	Almería
38;30	14;45	[0]	Cordova, Valencia
40	14;54	[0]	Toledo, Santarem
42	15; 8	[0]	Saragossa
66;25°	24	[0]	inscription—see the quote at beginning of this study

* Clearly a scribal error for 13;58, which is accurate

1.3.5b—#1079—Palermo MN (stolen)
Ibr. b. ʿAbd al-Karīm, undated
H/6° and A+/10°

20°	?
?	?
42	*Miṣr* (Cairo-Fustat)
?	?
39	?

Caldo mentions the mater (for 30°) and 2 plates for latitudes between 20° and 39°

1.3.6a—#117 – Madrid MAN
Ibr. b. Saʿīd al-Sahlī, Toledo, 459 H
H/3° and A/5°
23;51°

22°	13;21/10;39	[-1]	Mecca
25	13;35/10;25	[0]	Medina

30	13;58/10;2	[0]	*Miṣr* (Cairo-Fustat), Kirman, Sijilmasa, Siniz, Jannaba
32	14;8/9;52	[0]	Kufa, Sijistan, Jerusalem, Tiberias, Carthage, Shiraz, Alexandria, Fars, Ascalon, Rosetta, Tinnis, Ramla, Ahwaz, Kairouan, Ana, Tripoli (Libya), Barqa (! repeated), Istakhr, Gaza
33;10	14;14/9;46	[0]	Baghdad, Damascus, Fez, Babil, Tunis (!), Hit, Barqa (! repeated), Salé, Acre
35;30	14;15/9;45	[!]	Mosul, Rusafa, Manbij, al-Madaʾin, Cyprus, Sicily, Ceuta (the latitudes in degrees and minutes of each of these localities are given above the names – see §**7**) – the length of daylight should be 14;27
36;30	14;33/9;27	[0]	Almería, Algeciras, Harran, Raʾs al-ʿAyn, Shahrazur, Samarqand
37;30	14;39/9;21	[0]	Seville, Málaga, Granada, Tudmir (Murcia), Sardinia, Shimshat, Edessa, al-Rayy
38;20	14;45/9;15	[+1]	Cordova, Baeza, Murcia, Jaen, Balkh, Jurjan
39;52	14;54/9;6	[+1]	Toledo, Talavera, Madrid, Calatrava, Uclés, Cuenca, Guadalajara, Azerbeijan, Akhlat
41;30	15;5/8;55	[+1]	Saragossa, Calatayud, Daroca, Lérida, Huesca, Barbastro

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1.3.6b—#118—Oxford MHS
Ibr. b. Saʿīd al-Sahlī, Toledo, 460 H
H/5° and A/9°, some z, a, b, t+
23;51°

21;40°	13;20,40	[-15”]	Mecca, Yamama
25	13;35	[0]	Yathrib = Medina
28;20	13;50	[0]	Qulzum, Madyan, Kabul, Tawiyus, Dalas
30	13;58	[0]	*Miṣr* (Cairo-Fustat), ʿAyn Shams (Heliopolis), Kirman, Kandahar, Mahruban
33	14;13	[0]	Baghdad, Damascus, Caesariya, Tunis (!!), Fez
35;30	14;27	[0]	Mosul, Rusafa, Manbij, Sicily, Ceuta
36;30	14;33	[0]	Almería, Harran, Samarqand, Raʾs al-ʿAyn, Shahrazur
37;30	14;39	[0]	Seville, Málaga, Granada, Bukhara, Edessa, Rayy
38;30	14;45	[0]	Cordova, Murcia, Baeza, Jaen, Marwarrudh, Balkh, Jurjan
40	14;54	[0]	Toledo, Talavera, Azerbeijan, Akhlat
41;30	15; 5	[+1]	Saragossa, alatayud, Huesca, Barbastro

1.3.6c—#123 = #1167—Rome OA
Ibr. b. Saʿīd al-Sahlī, Valencia, 463 H
A/3° and A/6°, z, a
23;51°

22	13;22	[0]	Mecca
25	13;35	[0]	Yathrib = Medina
28;20	13;50	[0]	Qulzum, Fayyum, Ahnas, Kabul, Tawiyus, Dalas
30	13;58	[0]	*Miṣr* (Cairo-Fustat), Kirman, Qandahar, ʿAyn Shams (Heliopolis), Mahruban
35;00	14;27,30	[+27″]	Tangiers, ?, Sicily, Manbij, ?, Mosul, Rusafa, ?
36;30	14;33	[0]	Almería, Harran, Samarqand, Raʾs al-ʿAyn, Shahrazur
37;30	14;39	[0]	?, ?, ?, ?, Mayyafariqin, ?
38;30	14;45	[0]	Cordova, Murcia, Baeza, Marwarrudh, Balkh, Jurjan
40	14;54	[0]	Toledo, ?, ?, Azerbaijan, Akhlat
41;30	15; 5	[+1]	Saragossa, Calatayud, Lérida, Rome (*Rūma*), Khwarizm

Two additional sets of markings, of which at least the second is by another maker

33	14;13	[0]	Baghdad, Damascus
34;30	-	-	Tlemcen

Plate of horizons, plate with trigonometric grids, possibly not original
Some localities are illegible on the available photos

1.3.7—#121—Kassel SKS
Ibr. b. al-Sahlī, Valencia, 478 H
H/6° and A+/10°, z, a, b, t+
23;51°

0°	12	[0]	"what is below the celestial equator", the Island of Ceylon, the Island of al-Yaqut and al-Jawhar
13	12;47	[0]	Aden
19	13;10	[0]	Yemen, Tabala
22	13;22	[0]	Mecca
25	13;35	[0]	Yathrib = Medina
30	13;58	[0]	*Miṣr* (Cairo-Fustat), Kirman, Mahruban
32	14; 8	[0]	Kairouan, Ascalon, Tiberias
33; 9	14;13	[-1]	Baghdad, Damascus, Caesariya

35;30	14;27	[0]	Manbij, Sicily, Ceuta, Mosul
36;30	14;33	[0]	Almería, Harran, Shumayshat, Samarqand (!)
37;30	14;39	[0]	Seville, Málaga, Granada
38;30	14;45	[0]	Cordova, Murcia, Baeza
39;30	14;50	[-1]	Valencia, Denia, Badajoz, Merida
40	14;54	[0]	Toledo, Calatrava, Uclés
41;30	15; 8	[+4]	Saragossa, Rome, Khwarazm

Also 66;30° and 72°

Rays for latitudes 38;30° and 41;30°

1.3.8a—#2527—Oxford MHS

M. b. Saʿīd al-Ṣabbān, Guadalajara, 474 H

H/6° and A+/10°, t+, some t-, z, a, b

21;40°	Mecca, Yamama, Taif, Kuku
42	*Miṣr* (Cairo-Fustat), Kirman, Madyan, **al-xmdxxh** (where x represents an unpointed carrier) (??)
31;30	Alexandria, Kufa, Basra, Damietta, Sabur, **Bistam (??!)**
33;10	Baghdad, Fez, Damascus, Ascalon, Ifriqiyya, Tunis (!!)
36;30	Almería, Samarqand, Raʾs al-ʿAyn, Harran, Tarsus, Massisa, Raqqa, Hamadan
37;30	Granada, Málaga, Sardinia, Azerbeijan, Nishapur, Anbar (!), Bukhara, Edessa
38;30	Cordova, Salobrena, Seville, Marseilles, Ibiza, Homs (!)
39;30	Valencia, Badajoz, Denia, Malatya
42	Toledo, Santarem
42	Saragossa, Tortosa, Rome (*Rūmiya al-kubr*[*ā*])

Rays for Saragossa and Valencia

1.3.8b—#1139—Munich BNM

M. b. Saʿīd al-Ṣabbān, 466 H

H/6° and A/10°, t+, t-, z, a

-

21;30°	Mecca, Yamama
30	*Miṣr* (Cairo-Fustat), Tarsus (!!), Kirman (misspelled)
32	Kairouan, Kufa, Tiberias
33	Baghdad, Jerusalem
35;30	Ceuta, Sicily, Mosul, Rusafa
36;30	Almería, Málaga, Raʾs al-ʿAyn, Samarqand
37;30	Seville, Granada
38;30	Cordova, Murcia, Baeza, Jaén
39;30	Valencia, Badajoz, Denia

40	Toledo, Azerbeijan
41;30	Saragossa, Lérida

1.3.9—#2572—Washington NMAH

M. ibn al-Sahlī, Valencia, 483 H

H/6° and A/10°

23;51°

0°	Equator (daylight 12^h)
18	The (capital) city of China
21;30	Mecca
24	Medina
27	Akhmim
36	Almería, C4
37;30	Seville, Málaga, Granada (daylight $14;39^h$ [0])
42	Saragossa
66	-

Seasonal hours are labelled animal, vegetable or mineral.

1.3.10—#4040—PC

Unsigned, undated

H/6° and A/9°, z, a, b, t+

23;33°—see below

-16;30°	**"behind the equator in the south, latitude 16;30°"**
23	Mecca, Jedda, Taif, Yamama, Siraf, al-Mansura in China (!)
25	Yathrib = Medina, Hajar, Bahrein
30	*Miṣr* (Cairo-Fustat), Kirman, Siniz (near Ahwaz), ʿAyn Shams (Heliopolis)
32	Kairouan, Tiberias, Ascalon, Alexandria
33	Baghdad, Hit, Damascus, Tunis (!), Salé
35	Ceuta, Tangiers, Sicily, Mosul, **m-l-ẓ w-f-r** (?)
36	Almería, Harran, Samarqand, Raʾs al-ʿAyn
37;30	Seville, Málaga, Granada, Bukhara, Rayy
38;30	Cordova, Marseilles (!! maybe my misreading of Messina), Marwarrudh, Balkh, Jurjan
45	Constantinople, Burjan (???)

Astrological houses for latitude 35°. Plate of horizons bears a scale showing obliquity 23;33°

1.3.11—#1099—Nuremberg GNM

Aḥmad b. M. al-Naqqāsh, Saragossa, 472 H

H/6° and A/9°, some z, a, b, t- added later

21;30°	Mecca, Taif, Yamama, Beja
25	Medina
31	Alexandria, Damietta, Shapur
33	Baghdad, Damascus, Fes, Ascalon
34;30	Menorca (!!), Aleppo (!), Antioch (!), Basra (!!)
35	Ceuta, Sicily, Mosul, Rusafa
36;30	Almería, Samarqand, Harran, Raʾs al-ʿAyn
37;30	Seville, Granada, Anbar (!)
38;30	Cordova, Jaén, Jurjan, Balkh
39;30	Valencia, Badajoz, Majorca
41;30	Saragossa, Huesca, Calatayud

1.3.12a—#2572—Washington NMAH
Unsigned, undated
H/6° and A+/10°, z, a, t+, t-

37° Granada and 38° Seville (on the same plate !)
38;30 Cordova

Seasonal hours marked animal, vegetable and mineral

1.3.12c—#154—Chicago AP
Unsigned, undated
H/6° and A/10°, t-
23;51°

Toledo	40°	14;51	[-3]
Burgos	42	15; 8	[0]

(d) Earliest European astrolabes (selected)

6.1.1—#3042—Paris IMA
Unsigned, [Catalonia], undated [10th C]
H/6° and A/10° (only on plate for 41;30°)

36	-
39	-
41;30	**Roma et Francia**
45	-
47;30	-

H/3° or H/6°

C1	12
C2	24
C3	30
C4	36
C5	41
C6	45
C7	48

6.1.2—#161—London BM
Unsigned, provenance uncertain, undated [13th? C]
H/?°

15°—23°—30°—36°—41°—45°—48°

6.1.3—#166—Oxford MHS
Unsigned, provenance uncertain [Italy?], undated [13th C]

6.1.4—#300—Oxford MHS
Unsigned, provenance uncertain [England?], undated [13th? C]
H/6° and A/10°

25°—30°—35°—40°—45°—48°
52°—55°—60°

6.1.17—#589—Bernkastel-Kues NKS
Unsigned, [Germany?], undated [13th C?]
H/?

C1	15°
C2	24
C3	30
C4	36
C5	41
C6	45
C7	48

6.2.1—#416—Greenwich NMM

Unsigned, [Catalonia], undated [13th C?]

Damietta	4	31°
Jerusalem	3	32
Africa	4	33
Tripoli	4	34
Ceuta	4	35
Sicily	5	38
Valencia	5	39
Segovia	5	40
Barcelona	6	41
Pamplona	6	42
Macedonia	3	43
Genoa	3	44
Milan	2	45
unnamed*	7	46

* actually markings are for [41°]

Notes: The place-names are in medieval Catalan. The information on the climates is confused.

6.2.2—#558—Nuremberg GNM

Unsigned, provenance uncertain,. undated [13th? C]

H/3° and A/10° or A/7;30°

16°—30°—36°—40°—45°—48°—52°

6.3.1—#162—London SA

Unsigned, [Catalonia], undated [13th C?]

H/5° and A/10°

32;30°	[Jerusalem]
38;30	[Cordova]
39;40	[Valencia]
41	[Barcelona? C5?]
42	[Gerona?]

6.3.2*—#4560—PC

Unsigned, [Toledo?], undated [14th C]

H/6° and A/10°

32;30°	[Jerusalem]
40	[Toledo?]
42	[Saragossa ?]
43	[?]
45	[Vienne?, Lyon?]
49;30	[Reims]

One original plate is missing; a replacement plate has inscriptions in Arabic and serves Algiers [*ca*. 35;30°] and [Mecca, *ca*. 21;30°]

6.4.6—#202—PC

Unsigned, [Picardy], undated [14th C]

H/5° and A/15°

24°—30°—36°—41°—45°—
48°—50°—51°

APPENDIX B: LIST OF INSTRUMENTS CITED IN THE TEXT

Note: The numbers denoted by the symbol # are those of the International Instrument Checklist (for medieval and Renaissance instruments) currently in preparation. Numbers from 1 to 3999 are those of Price *et al*., *Astrolabe Checklist*. New numbers are assigned as follows: 4001-4999 for additional astrolabes, 5001-5999 for quadrants, 6001-6999 for sundials, 7001-7999 for globes; 8001-8999 for miscellaneous; and 9001-9999 for fakes. The numbers preceded by § refer to the catalogue of medieval instruments currently in preparation in Frankfurt and are not yet definitive. Instruments with numbers less than #337 are treated in Gunther, *Astrolabes*. Other references are to literature in which the object in question has been catalogued or described in detail. For abbreviations in the statements of the provenance, see **XVIII**.

#2 Brescia, MEC, inv. no. 36—Byzantine astrolabe dated 1062 (§1.1.1)—see Gunther, *Astrolabes*, I, pp. 104-108 (no. 2), based on Dalton, "Byzantine Astrolabe" (1926), and now **XIIIa-4**.

#3 Oxford, MHS, inv. no. IC 3—astrolabe by Aḥmad and Muḥammad, sons of Ibrāhīm al-Iṣfahānī, dated 374 H and fitted with a replacement rete datable to the 12th century (§1.2.11)—see Gunther, *Astrolabes*, I, pp. 114-116 (no. 3), and now **XIIIc-10**.

#99 Paris, BNF, inv. no. Ge. A.324—astrolabe by Aḥmad ibn Khalaf (Baghdad, 10th century) (§1.2.3)—see Gunther, *Astrolabes*, I, p. 230 (no. 99), and now **XIIIc-2**.

#100 PLU, stolen from Palermo, MN—mater by Ḥāmid ibn ʿAlī dated 343 H (§1.2.9a)—see Mortillaro, "Astrolabio arabo" (1848), and the more accurate account in Caldo, "Astrolabi di Palermo", pp. 6-9, and now **XIIIc-8.1**.

#101 Florence MSS, inv. no. 1113—unsigned undated Abbasid astrolabe with later (19th-century?) additions by a European (the so-called "Astrolabe of Pope Sylvester II") (§1.2.7)—see Gunther, *Astrolabes*, I, pp. 230-232 (no. 101), and now **XIIIc-6**.

#109=#3459 New York, MMA, inv. no. 91.1.535—astrolabe by the Yemeni Sultan al-Ashraf dated 690 H (containing an Abbasid plate with additional markings in Greek) (§1.1.2a, 1.2.15b, 1.5.12)—see King, "Yemeni Astrolabe", now in **XIVa**.

#110=#135 London, BM, inv. no. OA+371—unsigned, undated astrolabe (10th century) with a rete in the early Andalusī "Abbasid" style (and additional markings by a European) (§1.3.2)—see Gunther, *Astrolabes*, I, pp. 244 (no. 110) and 280 (no. 135).

#111 Kuwait, PC—astrolabe by Ḥāmid ibn Khiḍr al-Khujandī dated 374 H (§1.2.10)—see King, "Kuwait Astrolabes", pp. 80, 82, 83-89 (no. 2), now in **XIIIc-9**.

#116 Berlin, SBOA, inv. no. 6567 (Sprenger 2050)—astrolabe by Muḥammad ibn al-Ṣaffār dated 420 H (§1.3.3b)—see Gunther, *Astrolabes*, I, pp. 251-252 (no. 116), after Woepcke, "Arabisches Astrolab" (1855).

#117 Madrid, MAN, inv. no. 50762—astrolabe by Ibrāhīm ibn Saʿīd al-Sahlī dated 459 H (§1.3.6a)—see Gunther, *Astrolabes*, I, pp. pp. 252-253 (no. 117), and García Franco, *Astrolabios en España*, pp. 229-235 (no. 12).

#118 Oxford, MHS, inv. no. IC118—astrolabe by Ibrāhīm ibn Saʿīd al-Sahlī dated 460 H (§1.3.6b)—see Gunther, *Astrolabes*, I, pp. 253-256 (no. 118).

#121 Kassel, SKS, inv. no. A38—astrolabe by Ibrāhīm ibn al-Sahlī dated 478 H (§1.3.7)—see Gunther, *Astrolabes*, I, p. 263 (no. 121).

#122 Florence, MSS, inv. no. 1105—astrolabe by Muḥammad ibn Abi ʻl-Qāsim al-Iṣfahānī al-Ṣāliḥānī

dated 496 H (§1.2.12)—see Gunther, *Astrolabes*, I, p. 263 (no. 122), and now **XIIIc-11**.

#123 Rome, OA, inv. no. ?—astrolabe by Ibrāhīm ibn Saʿīd al-Sahlī dated 463 H (§1.3.6c)—unpublished.

#135 See #110.

#154 Chicago, AP, inv. no. M-36—astrolabe by Muḥammad ibn Yūsuf ibn Ḥātim, dated 638 H (§1.6.3), with a spurious plate (§1.3.11e)—see Gunther, *Astrolabes*, p. 300 (no. 154), and *Chicago AP Catalogue*, II, to appear..

#161 London, BM, inv. no. 1961 12-1 1—unsigned, undated astrolabe for the seven climates (§6.1.2)—see Gunther, *Astrolabes*, I, p. 306 (no. 161); and *London BM Catalogue*, pp. 110 and 112 (no. 323).

#162 London, SA, inv. no. Cat. 559—astrolabe with a rectangular frame inside the ecliptic on the rete and plates for latitudes down to that of [Palestine] (§6.3.1)—see Gunther, *Astrolabes*, I, pp. 306-309 (no. 162), based on Read (1893), and, more recently, King & Maier, "London Catalan Astrolabe".

#166 Oxford, MHS, inv. IC 166—Italian astrolabe with plates for the climates (§6.1.5)—see Gunther, *Astrolabes*, I, pp. 316-317 (no. 166).

#167 London, BM, inv. no. 67 7-5 22—Italian astrolabe for the climates (§6.1.6)—see Gunther, *Astrolabes*, I, p. 317 (no. 167); and *London BM Catalogue*, p. 114 (no. 329).

#169 Oxford, MHS, inv. no. IC 169—unsigned, undated Italian astrolabic plate for the 2nd climate and a rete of the "myrtle" variety combining northern and southern projections (§6.1.9)—see Gunther, *Astrolabes*, I, pp. 319-320 (no. 169), and King, "Italian Astrolabe", now in **XIIId**.

#191 Oxford, MHS, inv. no. IC 191—Spanish (?) astrolabe (for Saragossa and other latitudes, with later additions for Paris) (§6.2.4)—see Gunther, *Astrolabes*, I, pp. 340-341 (no. 191).

#202 PC—late-14th-century Picard astrolabe bearing monastic ciphers, with an inscription by Berselius dated 1522 (§6.4.6)—see King, *The Ciphers of the Monks*, pp. 131-151 and 406-419.

#291 London, BM, inv. no. 1909 6-17 1—Anglo-French astrolabe with plates for Montpellier, Oxford and elsewhere, dated 1326 (§6.6.2)—see Gunther, *Astrolabes*, I, pp. 465-467 (no. 291); and *London BM Catalogue*, pp. 112-113 (no. 325).

#299 Oxford, Museum of the History of Science, inv. no. 55-35—14th-century English astrolabe ("The Painswick astrolabe") (§6.6.3)—see Gunther, *Astrolabes*, II, pp. 475-476 (no. 299).

#300 Oxford, MHS, inv. no. IC 300—English or French astrolabe for latitudes between 24° and 60°, including for [Paris] and [London] (§6.1.4)—see Gunther, *Astrolabes*, I, p. 477-478 (no. 300).

#303 Oxford, MC—English mater with plates for the climates (§6.1.16)—see Gunther, *Astrolabes*, I, p. 482 (no. 303).

#416 Greenwich, NMM, inv. no. A21/NA36-21c—unsigned, undated Catalan astrolabe from *ca*. 1300 (§6.2.1)—previously unpublished; see King & Maier, "London Catalan Astrolabe", pp. 694-695; and *Greenwich Astrolabe Catalogue* (forthcoming).

#420 Greenwich, NMM, inv. no. 39.693.A43—medieval French astrolabe for the upper climates (§6.1.7)—unpublished; see *Greenwich Astrolabe Catalogue* (forthcoming).

#558 Nuremberg, GNM, inv. no. WI 282—medieval European astrolabe of uncertain provenance with plates for latitudes from 16° to 52° (§6.1.14)—see King, "Nuremberg Astrolabes", II, pp. 574-576 (no. 1.72).

#589 Bernkastel-Kues, NKS, inv. no. 3—mater and plates for the climates owned by Nikolaus of Cusa (§6.1.17)—see Hartmann, "Instrumente des Nikolaus Cusanus".

#640 PC—astrolabe dedicated by Ioannes (Regiomontanus) to Cardinal Bessarion in 1462 (§6.9.3)—see King & Turner, "Regiomontanus' Astrolabe".

#1026 Oxford, MHS, inv. no. 57-84/155—undated astrolabe (10th century) by Khafīf (§1.2.2a)—see *Oxford MHS Billmeir Supplement Catalogue*, pp. 16-18 (no. 155), and now **XIIIc-1.1**.

#1079 Palermo, MN, inv. no. ? (stolen)—an undated astrolabe by Ibrāhīm ibn ʿAbd al-Karīm (§1.3.5b)—unpublished.

#1099 Nuremberg, GNM, inv. no. WI 353—astrolabe by Aḥmad ibn Muḥammad al-Naqqāsh dated 472 H (§1.3.11)—see King, "Nuremberg Astrolabes", II, pp. 568-570 (no. 1.70).

#1130 Cairo, MIA, inv. no. 15351—an undated mater by Nasṭūlus (§1.2.4b)—previously unpublished; see now **XIIIc-3b**.

#1139 Munich, BNM, inv. no. 33/243—astrolabe by Muḥammad ibn Saʿīd al-Ṣabbān dated 496 H or 466 H (§1.3.8b)—see *Munich Astrolabe Catalogue*, pp. 145-159 (no. 1).

#1167 See #123.

#1179 PLU, formerly Berlin PC—undated astrolabe (10th century) by Muḥammad ibn Shaddād (al-Baladī) with a later Maghribi rete (§1.2.5)—see Dorn, "Drei arabische Instrumente", pp. 461-464, and now **XIIIc-4**.

#2527 Oxford, MHS, inv. no. 57-84/157—astrolabe by Muḥammad ibn Saʿīd al-Ṣabbān dated 474 H (§1.3.8a)—see *Oxford MHS Billmeir Supplement Catalogue*, pp. 18-19 (no. 157).

#2529 Oxford, MHS, inv. no. 57-84/156—a solitary rete attributable to Khafīf (§1.2.2b)—see *Oxford MHS Billmeir Supplement Catalogue*, p. 18 (no. 156), and now **XIIIc-1.2**.

#2572 Washington, NMAH, inv. no. 318178—astrolabe by Muḥammad ibn al-Sahlī dated 483 H with a replacement rete bearing Hebrew inscriptions (§1.3.9)—see *Washington NMAH Catalogue*, pp. 174-177 (no. 2752) (with illustrations of the front and back) (also mentioned in my "Review"); Goldstein & Saliba, "Astrolabe with Hebrew Star Names" (with more illustrations); and now Lacerenza, "Il ragno ebraico dell'astrolabio di Ibn al-Sahlī".

#3042 Paris, IMA, inv. no. AI 86-31—unsigned, undated astrolabe from Catalonia, late or early 10th century (§1.6.1)—see Stevens *et al*., eds., *The Oldest Latin Astrolabe*, and *Vernet Festschrift*, II, pp. 655-672, and also **XIIIa-9**.

#3459 See #109

#3501 Kuwait, DAI, inv. no. LNS 36M—astrolabe by (Muḥammad ibn ʿAbdallah known as) Nasṭūlus, dated 315 H (§1.2.4a)—see King, "Kuwait Astrolabes", pp. 79-83 (no. 1), now in **XIIIc-3.1**.

#3522 See #4180.

#3527 See #4180.

#3549 See #4180.

#3622 Cracow, JUM, inv. no. 4037—35/V—unsigned Andalusī astrolabe dated 446 H, with later inscriptions in Catalan (§1.3.4)—see, most recently, Maier, "Astrolab aus Córdoba".

#3650 Edinburgh, RSM, inv. no. T1959-62—mater and plates Muḥammad ibn al-Ṣaffār dated 417 H, fitted with a later Eastern Islamic rete (§1.3.3a)—unpublished.

#3702 Baghdad, AM, inv. no. 9723—an early (8th- or 9th-century?) astrolabe with some replacement markings probably by Aḥmad ibn Kamāl, whose name is engraved on the throne in the same late Ottoman hand (§1.2.1)—see Stautz, "Die früheste Formgebung der Astrolabien", with references to an earlier study by Faransīs & Naqshbandī, "Baghdad Astrolabes", and now **XIIIb**.

#3713 Cairo, MIA, inv. no. 15352—mater by Ḥāmid ibn ʿAlī with an illegible date [3]?4 H, replacement rete and plates (§1.2.9b)—previously unpublished; see now **XIIIc-8.2**.

#3714 Fez, DB, inv. no. ?—a mater by Ibrāhīm ibn ʿAbd al-Karīm dated 458 H (§1.3.5a)—unpublished.

#3904 See #4180.

#3919 See #4180.

#4020 London, PC—a badly-corroded 10th?-century Eastern Islamic astrolabe (§1.2.14)—previously unpublished; see now **XIIIb-4**.

#4021 Copenhagen, DS—a solitary 10th?-century Eastern Islamic plate with ogival markings (§1.2.13)—previously unpublished; see now **XIIIc-12.1**.

#4022 London, SM, inv. no. 1981-1380—an unsigned, undated (10th-century) Abbasid mater and plates (§1.2.8)—see *Linton Collection Catalogue*, p. 83, no. 160; and now **XIIIc-7**.

#4023 See #1130.

#4024 Paris, BNF, manuscript lat. 7412, fols. 19v-23v—astrolabe by Khalaf ibn al-Muʿādh illustrated in a Latin manuscript (§1.3.1)—see Van De Vyver, "Premières traductions"; and Destombes, "Astrolabe carolingien", pp. 23 and 41-43, and Kunitzsch, "10th-Century Astrolabe".

#4025 Palermo, MN, inv. no. ?—a solitary plate attributable to Muḥammad ibn al-Ṣaffār (§1.3.3c)—unpublished.

#4030 Florence, UG, inv. no. U1454A recto and verso—drawing by Antonio da Sangallo the Younger (1520) of an astrolabe by Khafīf (§1.2.2c)—see Saliba, "Astrolabe by Khafīf"; and now **XIIIc-1c**.

#4040 PC, Belgium—a set of plates from an 11th-century Andalusī astrolabe—see *Sotheby's London 30.5.1991 Catalogue*, p. 136 (lot 391).

#4180 Rockford, TM, inv. no. 507—undated (10th-century?) astrolabe by al-Muḥsin ibn Muḥammad al-Ṭabīb (§1.2.6) (previously numbered #3522, #3527, #3549, #3904 and #3919)—see *Rockford TM Catalogue*, pp. 60-63 (no. 1), and now **XIIIc-5**.

#4509 PC, Belgium—a medieval European astrolabe with a single plate with markings in Byzantine Greek (§1.1.2a)—unpublished.

#4518 PC, Belgium—a medieval English astrolabe (§6.6.11)—unpublished: see *Brussels SG 1984 Exhibition Catalogue*, p. 37 (no. 7); and King, *Ciphers of the Monks*, pp. 305 and 308.

#4523 PC, Germany—a Northern Italian astrolabe dated 1420—see Stautz, "Astrolab aus dem Jahr 1420".

#4560 PLU—a 14th-century Spanish astrolabe with inscriptions in Hebrew, Latin and Arabic (§6.3.2*)—see King, "Medieval Spanish Astrolabe with Inscriptions in Latin, Hebrew and Arabic", now in **XV**.

Part XVII

The quatrefoil as decoration on astrolabe retes

To the memory of Myron Bement Smith

DEDICATION,
ACKNOWLEDGEMENTS AND NOTES ON THIS VERSION

This study is dedicated to the memory of a historian of Islamic architecture and culture who inspired me to pursue my graduate studies in one of the best departments of Near Eastern Languages and Literatures in the world. Myron Bement Smith (1897-1970), then based at the Library of Congress, was looking for an assistant to help organize his "Islamic Archive", including hundreds of slides of Islamic architecture. (This collection is now in the Freer Gallery of Art and Arthur M. Sackler Gallery Archives.) In 1968 I had an introduction to Myron B. Smith from Dr. Doug Tushingham of the Royal Ontario Museum in Toronto and I drove down from Toronto to Washington to meet him. We both soon realized that neither his nor my interests would be well served by my organizing his slides, and he suggested that I apply for graduate studies at a series of American universities that he favoured: Yale, Harvard, Columbia and Michigan. On the way back to Toronto, I visited Yale, met with Professors Franz Rosenthal and Marvin Pope, and within a few months was established there.

Years later, when I was working on published plans of Islamic architecture at the Institute of Fine Arts in New York, I found to my pleasure that the plans prepared by Myron B. Smith were amongst the only ones in the entire corpus of published literature on Islamic architecture that were correctly oriented, so that I could be confident of the actual orientations of various mosques and madrasas (see **VIIa**). Myron Smith had taken the trouble to state precisely how he had established the directions of the true north pointers on his plans.

In the published literature on astronomical instruments the reader will find several descriptions of astrolabes with quatrefoil decoration in which the quatrefoils are ignored altogether. But they have a message for us. This study is intended as a small contribution by a historian of Islamic science to a topic of interest to the history of Islamic and medieval European art. Maybe now these quatrefoils will be taken seriously. Parts of this study appeared as an appendix "The Quatrefoil on Medieval Astrolabe Retes" in my *The Ciphers of the Monks—A Forgotten Number Notation of the Middle Ages*, Stuttgart: Franz Steiner, 2001, pp. 380-390, but since that study was primarily concerned with medieval *European* astrolabes, I have here expanded the section on *Islamic* astrolabes with quatrefoil decoration to include all significant examples.

Do we need a study of these quatrefoils by a historian of Islamic science? In response, I would just like to point out that in all of the secondary literature on medieval European art known to me, not a single medieval European astrolabe is featured. Most recently, even in the splendid exhibition "Gothic—Art for England 1400-1547", held at the Victoria and Albert Museum, London, in 2003, not a single English astrolabe was included.

About a dozen years ago, I worked to put together a book-length manuscript entitled *Ciphers, Monks and Virgins—Forgotten Episodes in Medieval History*. Perhaps naïvely, I thought that

this might be of interest to people who cared to read about new topics in medieval European science, art and religion. In this work, I attempted to present:

(1) a forgotten number-notation of *ciphers* used by *monks* all over Europe in the Middle Ages, admittedly in very limited circles;
(2) an *astrolabe* with *quatrefoil* decoration bearing these *ciphers* from 14th-century Picardy, that was later owned by a Humanist *monk* in 16th-century Liège who also possessed one of the most beautiful statues of the *Virgin* and Child; and
(3) a *virgin* saint from 14th-century Flanders whose cult spread all over Europe and whose images—a bearded woman on a cross—have confused both believers and scholars over the centuries, to such an extent that the accounts of her in serious and popular dictionaries of saints are mainly absurd.

I found no interest in this book amongst potential publishers, and so I have published sections of it elsewhere.* Here, then, is the part on quatrefoils.

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* On the *ciphers*, which were originally used mainly in Cistercian circles, see my *The Ciphers of the Monks — A Forgotten Number-Notation of the Middle Ages*, Stuttgart: Steiner, 2001. The *ciphers* are featured on an *astrolabe* from medieval Picardy. On this *astrolabe* in the context of medieval French instrument-making, see *ibid*., pp. 131-142 and 391-419. On its *quatrefoil* decoration see *ibid*., pp. 380-390 and 406. The *astrolabe* was eventually owned by a Benedictine *monk*. On the *monk* and his Humanist connections see *ibid*., pp. 143-151. On the same *monk*'s magnificent statue of the *Virgin* see *ibid*., pp. 420-426. Now the *monk* worked for a bishop-prince who erected an altar to a crucified bearded *virgin saint*, whose cult has been seriously misunderstood by historians and is usually completely distorted in the modern literature. On her see now my study "The Cult of St. Wilgefortis in Flanders, Holland, England and France", in *Am Kreuz – Eine Frau: Anfänge – Abhängigkeiten – Aktualisierungen*, Sigrid Glockzin-Bever and Martin Kraatz, eds., in *Ästhetik – Theologie – Liturgik* (Münster: LIT Verlag) 26 (2003), pp. 55-97.

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0 Introductory remarks

> "The small quatrefoil (on rete of the Society of Antiquaries' astrolabe) is an interesting survival of great antiquity." R. T. Gunther, *Astrolabes of the World* (1932), II, p. 307, on the Catalan astrolabe from *ca*. 1300 (#162—see **Fig. 3.1**).
>
> "Quatrefoil: ... A characteristic device in Byzantine decoration and Gothic tracery and carving, that regained popularity in the Gothic revival. Sometimes stated to be based on the four-leafed clover; reliable authorities believe the quatrefoil to be a strictly Christian motif—a form of Greek cross with rounded ends, or of the nimbus with four arcs representing the four Evangelists. ... ." M. Stafford & D. Ware, *Dictionary of Ornament* (1974), p. 176.
>
> "Pässe gehören zu den Standardformen der Gotik. Sie kommen während des 13. und 14. Jahrhunderts fast überall vor. ... . Der weitaus häufigste aller Pässe ist allerdings der Vierpaß. Er symbolisiert die irdische Sphäre als solche—die aus vier Elementen bestehende, nach vier Himmelsrichtungen ausgedehnte, den vier Winden und dem Zyklus der vier Jahreszeiten unterworfene, von vier Temperamenten belebte und ihrer sozialen Ordnung von der Geltung der vier Kardinaltugenden (Gerechtigkeit, Starkmut, Klugheit und Mäßigkeit) abhängige Welt. Dem Vierpaß konnte alles eingebettet werden, was mit dem Leben auf Erden zusammenhängt und sich im Irdischen abspielt ... ." A. Perrig, *Ghiberti's Paradiesestür* (1987), pp. 35-36.

The quatrefoil as a decorative feature on medieval astrolabes provides an example of the importance of these objects as scientific works of art.[1] It is common knowledge that the quatrefoil and trefoil dominant features in Gothic architecture; they are widely used in Andalusī decorative art,[2] and they are found in Christian Spain (Toledo and Burgos), and especially in France, from about 1200 onwards.[3] They appear but rarely in Romanesque architecture, and some examples that come to mind have been labelled later additions. But less well known is the fact that there are numerous examples of quatrefoils in European art, if not architecture, from the 10th century to the 12th: they are found on reliquaries, altars, and book illuminations.[4] Yet the quatrefoil is also a Byzantine and

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[1] On symbolism, religious and secular, in medieval European art and architecture the following sources are available. A useful dictionary, arranged alphabetically by type, and deliberately made simple enough for a child to understand, is Ferguson, *Signs & Symbols in Christian Art*. See also Hulme, *Symbolism in Christian Art*. Also valuable, and not restricted to religious motifs, is Stafford & Ware, *Dictionary of Ornament*. Lexicons of religious symbolism prepared by religious savants such as Beigbeder, *Lexique des symboles*, and De Champeaux & Sterckx, *Symboles*, contain remarkably little of real importance and nothing of relevance to this study. On Gothic architecture, sculpture and painting in general, see, for example, Deuchler, *Gothic*, richly illustrated and with a useful bibliography.

[2] For decorative art in Andalusī architecture the best study is Pavón Maldonado, *El arte hispanomusulman*. On the quatrefoil and variations thereon see *ibid*., pp. 69-75, and figs. 98, 102, 104 (no. 23), and pls. XLIIb and CLXII (Alcázar, Seville), CLXXIV (Casa de Pilatos, Seville), and CLXXXIV (Madīnat al-Zahrāʾ).. For quatrefoil decoration in Hispano-Mauresque art, which does not specifically concern us here, see also **XV-3.26**.

[3] On the quatrefoil in Gothic art and architecture see Deuchler, *Gothic*, p. 8, and also the penetrating remarks in Perrig, *Ghiberti's Paradiesestür*, pp. 35-36, quoted above. Another important study is Baltrušaitis, *Le Moyen Âge fantastique*, pp. 102-107, translated in *Das phantastische Mittelalter*, pp. 127-133. In this last-mentioned work, several examples of Islamic, Byzantine and European quatrefoils are compared. Most reference works on medieval art and architecture take the quatrefoil for granted (as does Deuchler).

[4] Yet earlier quatrefoils are found on a 7th-century pendant from Ash, Kent, which has a "spotted quatrefoil knot" at the centre of an equal-armed cross, and on the Strickland brooch, a magnificent piece of Anglo-Saxon jewellery dated to the mid 9th century (*London BM 1984 Exhibition Catalogue*, p. 25, no. 8, and pp. 232-233, no. 189). An 11th-century Latin *Evangelistarium* of uncertain provenance contains an illustration of the 12 apostles around a dove representing the Holy Spirit, with the apostles arranged in four groups in the leaves of a quatrefoil (Vöge, *Deutsche Malerschule*, pp. 142-143, and p. 274 and Abb. 34). There is also a quatrefoil on the title-page

an Islamic motif, and in its manifestation in Gothic art and architecture, it came to Europe *via* Spain. One of the other vehicles by which the quatrefoil was introduced into Europe was the astrolabe. We can in fact trace this specific case of transmission more easily than we can trace the influences behind the appearance of the quatrefoil in European art and architecture generally.

The quatrefoil appears to be originally a Byzantine motif that is, however, not widely attested in Byzantine art and architecture. There it occurs in a floral, strictly decorative, context, rather than as a symbolic motif as it is usually interpreted in the medieval European context.[5] The quatrefoil was not widely adopted in Islamic art and architecture, except in al-Andalus, that is, that part of the Iberian peninsula that was under Muslim domination at any given time, although we shall have occasion to mention one surviving Latin astrolabe from 14th-century Toledo (see below and also **XV**). But even in Eastern Islamic decorative art,[6] there was one notable exception to this, namely, the quatrefoils on a sub-group of Eastern Islamic astrolabes. Already Robert Gunther in the early 1930s realized the significance of the presence of these quatrefoils.[6a]

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of the *Evangelium* of Kaiser Otto III from Reichenau, *ca*. 1000 (*Cologne SM 1991 Exhibition Catalogue*, p. 22, 134 and 138, no. 36). Whilst the origin of these appears to be indigenous, another early quatrefoil on a 12th-century fresco in the Chapelle du Saint-Crucifix of the Cathédrale Notre-Dame du Puy at Le Puy-en-Velay (illustrated in Comte, *Le Puy-en-Velay*, p. 110), an important pilgrimage-centre in its own right and also a station on the road to Santiago de Compostela, may, in this case, indicate Byzantine influence. Some examples from other items of 12th- and 13th-century religious artefacts are featured in *Cologne SM 1985 Catalogue*, II, pp. 296-298, and 348, III, pp. 101-104, 163 and 167-168; and *London HG 1984 Exhibition Catalogue*, p. 278. On Gothic rose-windows see, for example, Möbius & Möbius, *Bauornament im Mittelalter*, pp. 91-110.

[5] For example, a quatrefoil, very botanical in appearance, is found as decoration on a house in Baqouza in Syria which goes back perhaps as far as the 4th century (*Dict. arch. chrét.*, II:1, cols. 469-478 (by H. Leclercq) especially cols. 473 and 478 (after Vogüé)). I have found the quatrefoil elsewhere in Islamic patterns only on a stucco relief frieze from the palace of al-Rāfiqa just outside the walls of al-Raqqa in Northern Syria, dated to *ca*. 835, and now preserved in the Archaeological Museum in Damascus (illustrated in *Washington 1985 Syria Exhibition Catalogue*, pp. 514-515, no. 256): on this frieze alternate four- and six-leaf medallions with external and internal foliate decoration are featured (for a hexafoil at Mshattā see the articles "Architecture" by K. A. C. Creswell in EI_2, pl. XIII, and "al-Mushattā" by Priscilla Soucek). The dating of the imposing decorations of Mshattā, a palatial, ruined structure some 35 km south of Amman, which include such foliate motifs, constitutes a severe problem for architecture historians, as yet unresolved, so I shall not dwell on these decorations here. More examples are given in Baltru·aitis, *op. cit*. Not a single quatrefoil is depicted in Evans, *The Arts of Byzantium*, so that one should beware of generalizations.

[6] At the Medieval Iraq Study Day held at the British Museum on May 15, 2004, Dr. Jessica Hallett (Lisbon) showed a quatrefoil on a decorated ceramic bowl from 9th-century Basra recovered in China. Dr. Hallett kindly informed that this is featured in her doctoral dissertation *Early Islamic Ceramics from Basra, Iraq*, (Oxford University, 1994), pl. 78a, and sent me pictures in less seconds than the months the bowl had taken to reach its final resting-place. However, and *con tutti rispetti*, al-Khujandī's quatrefoil (see **Fig. 1.1**) is far nicer, and more sophisticated, than the stylized pointed petals surrounding a central square that are found on this bowl. I would be interested to learn of any 9th- or 10th-century quatrefoils cut out of *metal*, be they on Byzantine or Islamic pieces. As yet, I have nothing with which to compare al-Khujandī's quatrefoil.

[6a] The remarks in Gunther, *Astrolabes*, I, pp. 114, 118, 237, 245 and 300, and II, pp. 307, 463, 469, *etc*. (in each case also the accompanying illustrations) are of interest. My own early investigations are recorded in King, "Astronomical Instruments between East and West", pp. 154 and 170; *idem*, "Kuwait Astrolabes", p. 85, now in **XIIIb-9**; *idem* & Maier, "London Catalan Astrolabe", pp. 680-682; and *idem*, *The Ciphers of the Monks*, pp. 380-390.

1 Eastern Islamic astrolabes

We can safely assume—although there is no direct evidence—that quatrefoils were also found on certain Byzantine astrolabes, all now lost, and that it was these that provided the inspiration for the earliest quatrefoils on Eastern Islamic astrolabes.[7] We find, for example, a prominent quatrefoil on

#111 the spectacular rete of the astrolabe of Hāmid ibn Khiḍr al-Khujandī, made in Baghdad in the year 374 H [= 984/85] (**Fig. 1.1**).[8]

There is, in fact, a series of astrolabes from the Islamic East up to the 17th century that exhibit this same feature, and they were clearly inspired by the al-Khujandī tradition. The first and third are from Isfahan, which in the late 10th and 11th centuries developed into an important centre of astronomy (see **XIIIc-10-11**):

#3 a replacement rete datable *ca*. 1100 on an astrolabe made in Isfahan in the late 10th century (**Fig. 1.2**);[9]

#2557 an astrolabe by Badr (ibn ʿAbdallāh), *mawlā* of Hibatallāh, dated 525 H [= 1130/31], probably in Baghdad (**Fig. 1.3**);[10]

#5 a geared astrolabe by Muḥammad ibn Abī Bakr ibn Muḥammad al-Rāshidī al-Ibarī al-Iṣfahānī, dated 618 H [= 1223/24] (**Fig. 1.4**);[11]

#2505 an astrolabe signed by Shams al-Dīn Muḥammad Ṣaffār in 911 H [= 1505/06] (**Fig. 1.5**),[12] whose various other instruments are also decorated with quatrefoils (see, for example, **Fig. XIIIc-8.2a**);[13] and

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[7] A parallel development is the use of a bird-shaped pointer for the star Vega. This occurs on Byzantine astrolabes, of which the only surviving example is:

#2, dated 1062 (Brescia, Museo dell'Età Cristiana, inv. no. 36—see Dalton, "Byzantine Astrolabe"; and Gunther, *Astrolabes*, I, pp. 104-108 (no. 2), based on Dalton; Stautz, "Die früheste Formgebung der Astrolabien", pp. 319-320; and **XIIIa-4**;

the earliest surviving Islamic astrolabe, from 8th- or early-9th-century Baghdad

#3702, (Baghdad, Archaeological Museum, inv. no. 9723)—see Fransis & Naqshbandi, "Baghdad Astrolabes", pp. 12-13 and pls. 2-3; Stautz, "Die früheste Formgebung der Astrolabien", pp. 320-322; and now **XIIIb**;

a few early Islamic astrolabes such as

#5, from Isfahan, dated 1223/24 (see n. 11 below),

and one of the earliest surviving European astrolabes,

#162, from Catalonia, *ca*. 1300 (see n. 21 below).

The bird becomes a common feature on late Islamic astrolabes, but falls out of use in Europe. It is worthy of note that on two of the above-mentioned examples (#5 and #162) we find a bird *and* a quatrefoil. On the latter the eagle has become a cock.

[8] Kuwait, private collection—see King, "Kuwait Astrolabes", pp. 80, 82, and 83-89, now in **XIIIc-9**.

[9] Oxford, Museum of the History of Science, inv. no. ICC3—see Gunther, *Astrolabes*, I, pp. 114-116 (no. 3) and pls. XXII-XXIII (astrolabe of the brothers Aḥmad and Muḥammad, sons of Ibrāhīm al-Iṣfahānī, dated 374 H), and now **XIIIb-10**.

[10] Chicago, Adler Planetarium, inv. no. A84—see *Chicago AP Catalogue,* II, in press.

[11] Oxford, Museum of the History of Science, inv. no. 2015—see Gunther, *Astrolabes*, I, pp. 118-120 (no. 5) and pls. XXV-XXVI.

[12] Oxford, Museum of the History of Science, inv. no. 57-84/158—see *Oxford MHS Billmeir Supplement Catalogue*, pp. 19-20 (no. 158) and pl. XVII, in which the quatrefoil is overlooked.

[13] On the other instruments see Mayer, *Islamic Astrolabists*, pp. 75-76. The rete in **XIIIc-8.2** is unsigned but clearly by Shams al-Dīn Ṣaffār. On one that has been published and illustrated see Gunther, *Astrolabes*, I, pp. 241-242 (*ad* #108), where the piece is misdated to 1288 and the quatrefoil is overlooked.

1.1

1.2

Fig. 1.3: The quatrefoil on the rete of an astrolabe by Badr (ibn ʿAbdallāh), *mawlā* of Hibatallāh, dated 525 H [= 1130/31] (#2557). [Courtesy of the Adler Planetarium, Chicago.]

#2708 an astrolabe by Wafāʾ-yi Munajjim, location uncertain, possibly India, dated 1017 H [= 1608/09] (**Fig. 1.6**).[14]

A single example from early-13th-century Syria shows a larger but less pronounced quatrefoil in a different position, namely, at the bottom of the rete. This is:

←
Fig. 1.1:The quatrefoil on the rete of the astrolabe made by al-Khujandī (#111) in Baghdad in the year 374 H [= 984/85]. The quatrefoil was surely inspired, not necessarily directly, by one on a Byzantine astrolabe. [Private collection, photo courtesy of the owner.]
Fig. 1.2: The quatrefoil on the replacement rete from *ca*. 1100 for a late-10th-century astrolabe made in Isfahan (#3). [Courtesy of the Museum of the History of Science, Oxford.]

[14] Point Lookout, New York, collection of Leonard Linton—see *Linton Collection Catalogue*, pp. 121-123 (no. 179).

Fig. 1.4: The quatrefoil on the rete of the geared astrolabe made in Isfahan in 618 H [= 1222/23] (#5). This is a different kind of quatrefoil from all the others featured here. The four *feuilles* are shaped more like horseshoes than the standard semi-circular protrusions around the sides of a hypothetical base square. This feature merits further investigation. [Courtesy of the Museum of the History of Science, Oxford.]

Fig. 1.6: The quatrefoil on an astrolabe by Wafāʾ-yi Munajjim dated 1017 H [= 1608/09] (#2708). [Photo from the archives of Alain Brieux, courtesy of Dominique Brieux.]

←
Fig. 1.5: The quatrefoil on a typical astrolabe by Muḥammad Ṣaffār, this one (#2505) dated 911 H [= 1505/06]. [Courtesy of the Museum of the History of Science, Oxford.]

#104 the magnificent astrolabe with zoomorphic decoration made by ʿAbd al-Karīm al-Miṣrī in Damascus in 633 H [= 1235/36] (**Fig. 1.7**).[15]

Inside the upper ecliptic we now find a knotted design, and whether by accident of design, a small quatrefoil and a small pentafoil are to be found in the middle of this.

Another example illustrates the fact that the same kind of quatrefoil decoration that we find on the astrolabe of al-Khujandī was in use in 14th-century Syria, and by chance influenced one particular instrument from mid-17th-century Lahore:

#4201 a universal astrolabe made in Lahore *ca*. 1650 (**Fig. 1.8**).[16]

This was copied from a universal astrolabe of the Aleppo astronomer Ibn al-Sarrāj *ca*. 1325, the leading instrument-maker of the late Islamic period.[17]

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[15] London, The British Museum, inv. no. 55 7-9 1—see Gunther, *Astrolabes*, I, pp. 236-237 (no. 104); and Michael Rogers in *Washington LC 1992 Exhibition Catalogue*, pp. 215-216 (no. 112), particularly useful on the inscription.

[16] London, Ahuan Gallery—see *Christie's London 4.10.1995 Catalogue*, pp. 20-21 (lot 61), and now **XIVg**.

[17] On Ibn al-Sarrāj and his universal astrolabe see now **XIVb-5**, and the references there cited.

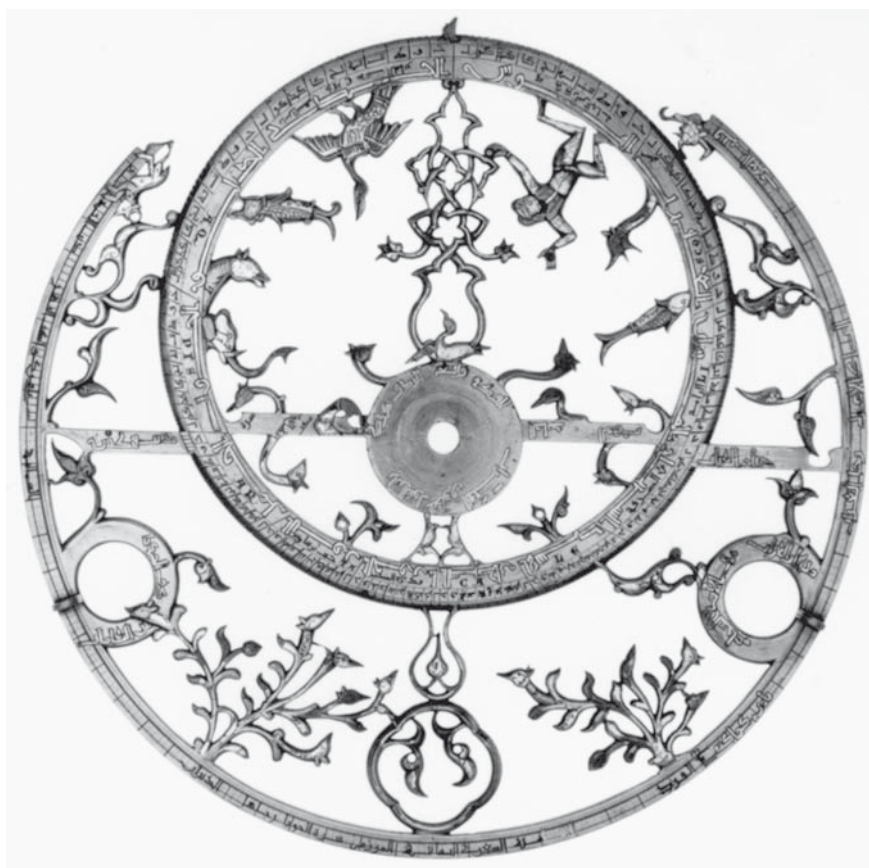



Fig. 1.7: Traces of a quatrefoil on lower rim of the rete of an astrolabe by ʿAbd al-Karīm al-Miṣrī in 633 H [= 1235/36] (#104). [Courtesy of the British Museum, London.]

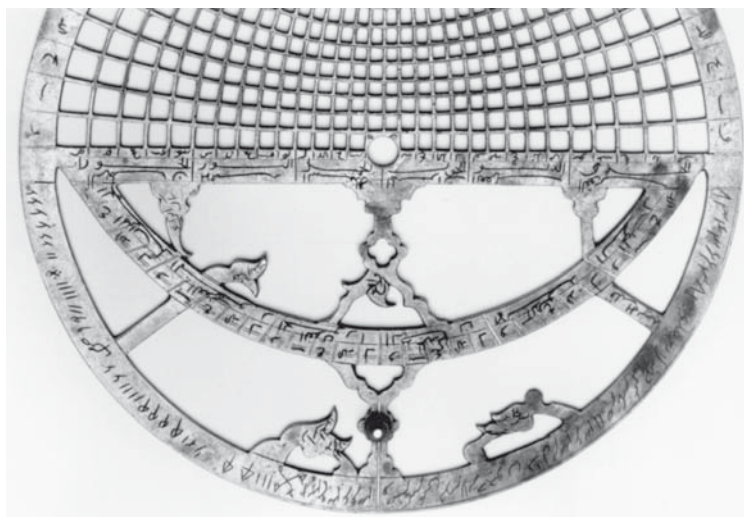
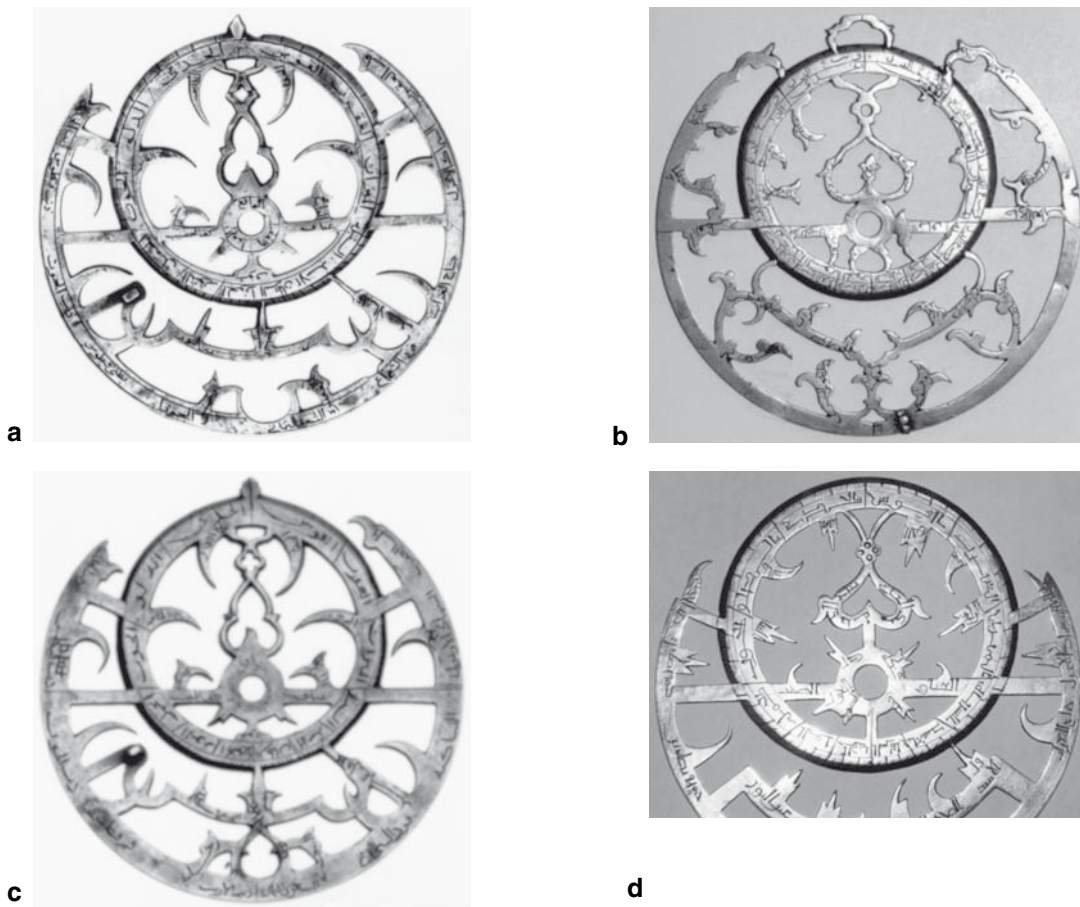



Fig. 1.8: The quatrefoil on the rete of a universal astrolabe made in Lahore in the middle of the 17th century (#4201), copied from a (lost) 14th-century Syrian universal astrolabe by Ibn al-Sarrāj that was decorated in the tradition of al-Khujandī. [Photo courtesy of Christie's of London.]

Figs. 1.9a-d: Quatrefoils on various retes on late (a-b), degenerate (c) and fake astrolabes (d).

Some degenerate quatrefoils are found on various late, degenerate or fake astrolabes: see **Figs. 1.9a-d**.[18]

2 Western Islamic astrolabes

Whilst no 10th- or 11th-century Andalusī astrolabes bear any quatrefoil decoration (and none survive from the 12th century), the rete of

#154 an astrolabe made by Muḥammad ibn Yūsuf ibn Ḥātim in 638 H [= 1240/41] (**Fig. 2.1**)[19]

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[18] For a good illustration of another degenerate quatrefoil, in the form of a circular ring, on a fake astrolabe, see *London Khalili Collection Catalogue*, I, p. 195 (no. 119), although the conclusions regarding the connection to al-Khujandī's astrolabe are incorrect (see my "Review", col. 257).

[19] Chicago, Adler Planetarium, inv. no. M36—see Gunther, *Astrolabes*, I, p. 300 (no. 154, misdated to 1747) and pl. LXVII, and *Chicago AP Catalogue*, II, in press.

Fig. 2.1: The quatrefoil decoration on the rete of an astrolabe made in al-Andalus in 638 H [= 1240/41] (#154). No other known instrument has two quatrefoils in this configuration. [Courtesy of the Adler Planetarium, Chicago.]

Fig. 2.2: A degenerate quatrefoil on an astrolabe by ʿUthmān ibn ʿAbdallāh al-Ṣaffār of Fez, dated 699 H [= 1299/1300] (#1077). The "*miḥrāb*" at the bottom of the rete is now inverted. [Courtesy of the Museo di Storia della Scienza, Florence.]

is embellished with two quatrefoils, a smaller one at the top and a larger one at the bottom. No other Western Islamic instruments with quatrefoils on the rete are known to me. The closest we come to a quatrefoil is on:

#1077 an astrolabe made by ʿUthmān ibn ʿAbdallāh al-Ṣaffār in Fez, dated 699 H [= 1299/1300] (**Fig. 2.2**),[20]

on which there is a degenerate one at the top of the upper equinoctial frame. See **Fig. XV-13b** on quatrefoil decoration on the *back* of a 14th-century astrolabe from Fez.

What the Muslim craftsmen saw in these quatrefoils is not clear. Surely, they did not recognize in them any kind of Christian symbol.

3 Medieval European astrolabes

One of the earliest surviving European astrolabes:

#162 an elegant Catalan piece from *ca*. 1300 (**Fig. 3.1**);[21]

exhibits a single quatrefoil on the rete in the same position as the one on al-Khujandī's astrolabe. Although the basic rete design is quite different, with a distinctive 'rectangular' frame inside the ecliptic, it is clearly Islamic in influence, and, most probably Byzantine in origin. Another piece,

#3915 a non-functional astrolabe from the Maghrib or al-Andalus, dating problematic, possibly *ca*. 1300, with inscriptions in Judaeo-Arabic, that is, Arabic in Hebrew script (**Fig. 3.2**),[22]

has a rete of very similar design, but with a degenerate quatrefoil, and it provides additional evidence that the design is Islamic rather than European.

Notice that:

#2041 a beautiful unsigned 14th-century French astrolabe (**Fig. XIIIc-9**),[23]

which otherwise exhibits various features of al-Khujandī's astrolabe, as well as the *miḥrāb*s of an Andalusī rete, does *not* feature a quatrefoil.

Furthermore,

#4560 a 14th-century astrolabe from Christian Spain with inscriptions in Hebrew, Latin and Arabic (**Fig. 3.3**),[24]

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[20] Florence, Museo di Storia della Scienza, inv. no. 1109—unpublished, see §1.6.5 of the Frankfurt catalogue.

[21] London, Society of Antiquaries, inv. no. Cat. 559—see Gunther, *Astrolabes*, II, pp. 306-309 (no. 162), and the detailed discussion in King & Maier, "London Catalan Astrolabe".

[22] London, Nasser D. Khalili Collection, inv. no. SCI158—see *Christie's Amsterdam 15.12.1988 Catalogue*, pp. 88-95 (lot 247); King & Maier, "Catalan Astrolabe", pp. 679 and 718; and *London Khalili Collection Catalogue*, pp. 214-217 (no. 124). In the last-mentioned work, the fact that the rete has the same design as that of #162 is overlooked, and the degenerate quatrefoil is ignored: see my "Review", col. 257 *ad* no. 124. In *Speyer 2004-05 Exhibition Catalogue*, p. 242, Michael Rogers again claims that the instrument can be used from Spain to Palestine, but this is true only if one knows that the plates are not engraved for the latitudes stated, since the inscriptions have been shuffled.

[23] Oxford, Museum of the History of Science, inv. no. 57-84/173—unpublished, illustrations of the front and back in Poulle, *Instruments du Moyen Âge*, 1983 edn., pp. 12 and 14.

[24] Present location unknown, last auctioned at Sotheby's, London, on 18.10.2001—see the detailed description in King, "The Toledo Astrolabe", now in **XV**.
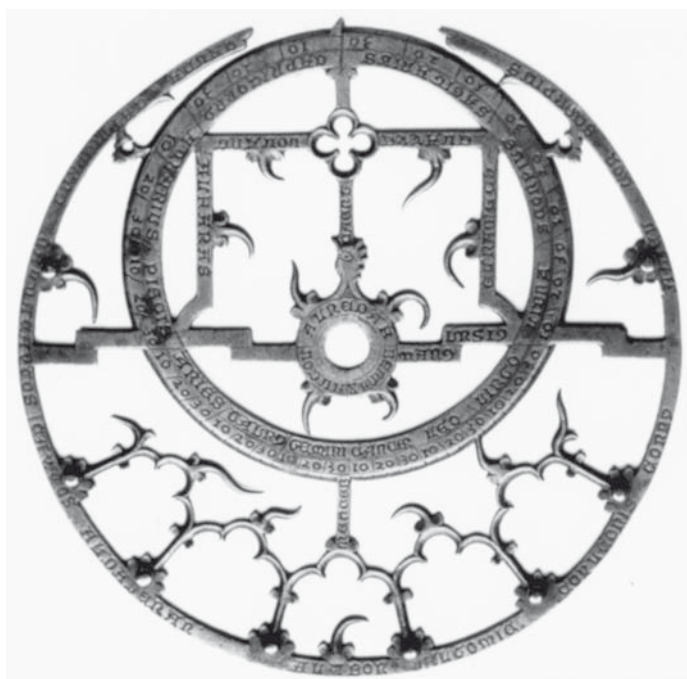
Fig. 3.1: The rectangular frame on this Catalan astrolabe from *ca*. 1300 (#162) may be originally from a Byzantine astrolabe, of which we have no trace amongst Islamic astrolabes. Certainly the frame looks as though it is crowned by the quatrefoil, almost as if it was made to bear it. [Photo by Professor Gerard L'E. Turner, courtesy of the Society of Antiquaries, London.]
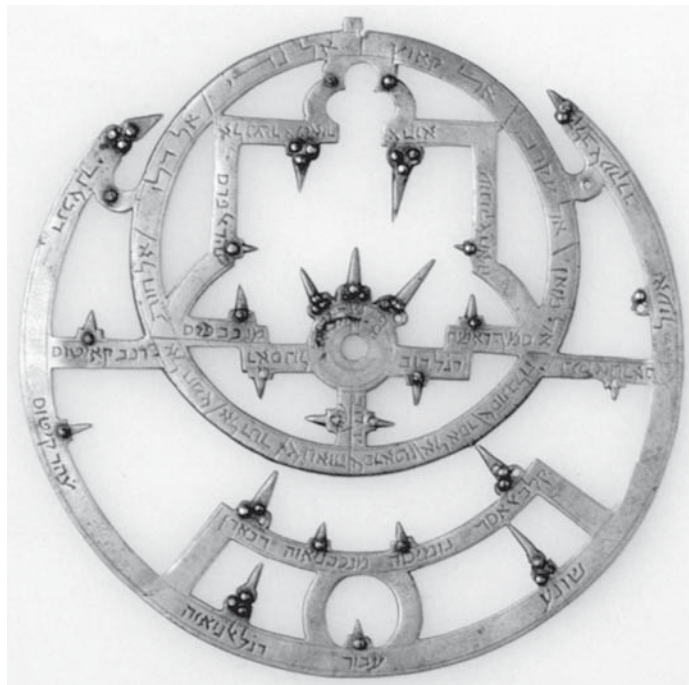
Fig. 3.2: The rete design of this astrolabe with Judaeo-Arabic inscriptions (#3915) was copied from another piece, not necessarily European but resembling the one shown in **Fig. 3.1**. Here the quatrefoil has degenerated. [Courtesy of Christie's, Amsterdam.]

Fig. 3.3: The rete of an astrolabe made in Christian Spain, most probably in Toledo, in the 14th century (#4560). This remarkable instrument bears inscriptions in Hebrew, Latin and Arabic. It appears to have been made by a Jewish and Christian craftsman working in collaboration, and was finished by a Spanish Muslim. The three half-quatrefoils are typical of Hispano-Mauresque decorative art and are here used in their original form, as carriers for star-pointers. [Photo courtesy of Christie's of London and a former owner.]

Fig. 3.4: The maker of this remarkable German astrolabe (#2027), whose dedicatee can be associated with Einbeck and the period 1322-42, included one large quatrefoil and five half-quatrefoils of the same size, one of which is on the throne. [Courtesy of the Jagiellonian Museum, Cracow.]

Fig. 3.5: On this English astrolabe dated 1342 (#292), the central quatrefoil is very prominent. The flame-shaped pointers, especially the double and triple pointers, indicate French influence. [Courtesy of the British Museum, London.]
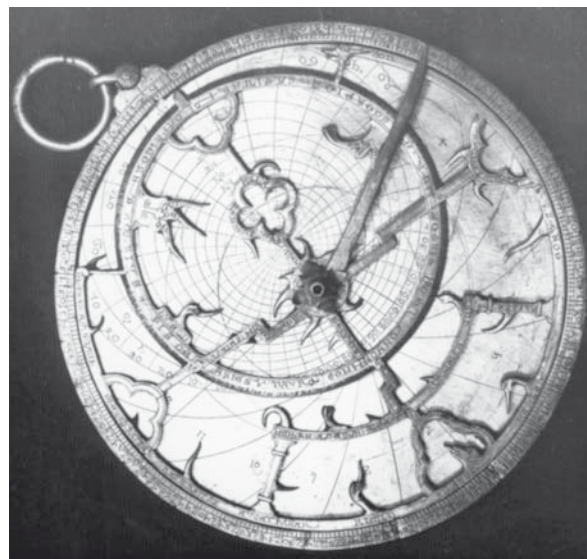
Fig. 3.6: On this English astrolabe (#4508), we find, in addition to the "central" quatrefoil, half-quatrefoils in the Hispano-Mauresque style at the ends of each of the horizontal and vertical axes, the one at the bottom being elongated upwards to accommodate the star-pointer. [Courtesy of the Bilim ve Teknoloji ve Teknik Müzesi, Istanbul.]
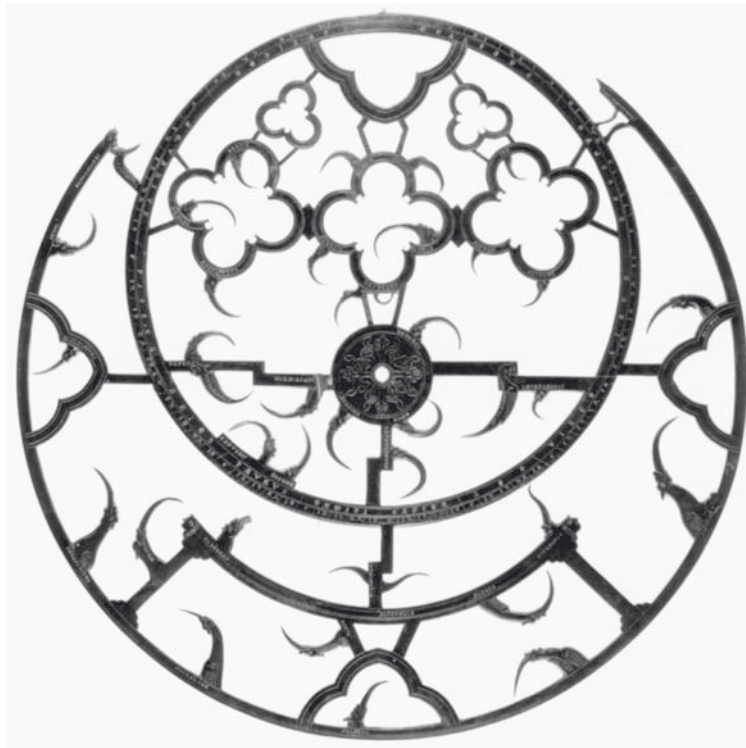
Fig. 3.7: The rete on the spectacular “Sloane astrolabe” of the British Museum, made in England *ca*. 1300 (#290). This is perhaps the oldest English astrolabe that survives. Not only the highly sophisticated rete-design but also the accuracy of the astronomical markings and the imposing size (diameter 46.5 cm) attest to how little we know about astrolabe-making in medieval England. [Courtesy of the British Museum, London.]

exhibits three quatrefoils attached to the inside of the upper ecliptic ring, each one supporting a single star-pointer.

The quatrefoil on astrolabe retes spread quickly in Europe during the 14th century, and its use was extended to other parts of the retes, such as the ends of the horizontal and vertical diameters. Numerous astrolabes of this kind survive, and I have listed them elsewhere.[25]

A fine example is the oldest *datable* German astrolabe:

#2072 signed by Ludolphus de Scicte, who was treasurer of the cathedral of Einbeck during 1322-42 (**Fig. 3.4**).[26]

Examples of two 14th-century English astrolabes exhibiting a single quatrefoil in the upper ecliptic, sometimes exaggerated, are:

[25] Namely, on the website www.uni-frankfurt.de/fb13/ign/instrument-catalogue.html, under 6.3 and 6.4.

[26] Cracow, Jagiellonian University Museum, inv. no. 41/V 4043 (?)—unpublished. On the identity of the maker see Härtel, “Ludolfus Borchdorp de Brunswik”. This is a fine example of detective work in archives assisting in identification of astrolabe-makers.

#292 dated 1342 and signed by one "Blakene", with a large quatrefoil and refined design, reflecting French influence (**Fig. 3.5**).[27]

#4508 with a small quatrefoil and the face of an ogre spanning three star-pointers on the upper left (**Fig. 3.6**),[28] typical of several such pieces with this design, and

Is this second piece really as early as the 14th century? We shall have to wait until all medieval English astrolabes are published, which will not be happening in the near future. It is rare but extremely useful to have a datable astrolabe when one is citing examples, because most of our dating rests on feel and intuition, and can sometimes be off by a century or two.[29]

Yet was the single quatrefoil original to these rete designs? The problem is that we find more than one quatrefoil used for the 'central' decoration on what is perhaps the earliest surviving English astrolabe, on which nobody has ever questioned a tentative dating to *ca*. 1300, namely:

#290 the magnificent Sloane astrolabe (**Fig. 3.7**).[30]

There is a half-quatrefoil at each end of the horizontal and vertical axes, and a splendid triad of quatrefoils is connected to the uppermost one of these by two trefoil frames. Any art historian would say that this was now typically "Gothic" decoration, and I would have to agree.

4 Medieval European astrolabes with inscriptions in Hebrew

Two astrolabes with Hebrew inscriptions also exhibit quatrefoils. The first of these is probably from Bologna, *ca*. 1400. The second may be from the same place, but is less carefully made, and therefore, probably later:[31]

#158 one with a regular half-quatrefoil below the lower equinoctial bar, and almost cruciform quatrefoils on the throne (**Fig. 4.1**);[32] and

#293 one with a large central quatrefoil, two half-quatrefoils below the ecliptic, and a trefoil on the throne (**Fig. 4.2**).[33]

5 Renaissance astrolabes

Occasionally we find a Renaissance astrolabe with a single quatrefoil in a prominent position, as on al-Khujandī's astrolabe. One such, actually the only one that has come to my attention, is:

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[27] London, British Museum, inv. no. 53 11-41—see Morley, *The Astrolabe of Shāh Ḥusayn*, pp. 45-46; Gunther, *Astrolabes*, I, pp. 468-469 (no. 292); and *London BM Catalogue*, p. 113 (no. 326).

[28] Istanbul, Bilim ve Teknoloji ve Teknik Müzesi, inv. no. 002—unpublished; see §6.4.14 of the Frankfurt catalogue. On the "face" on various other English astrolabes see Gingerich, "Zoomorphic Astrolabes", p. 95.

[29] On the problems of dating medieval European astrolabes see the references cited in n. 37 in **XIIIa**.

[30] London, British Museum, inv. no. Sloane 1—see Gunther, *Astrolabes*, II, pp. 463-465 (no. 290) and pls. CXXVI-II; and *London BM Catalogue*, p. 112 (no. 423).

[31] This happened in medieval Europe as well as in the Islamic world.

[32] London, British Museum, inv. no. 93 6-16 3—see Gunther, *Astrolabes*, I, p. 304 (no. 158: "Spanish Jewish"), and *London BM Catalogue*, pp. 113-114 (no. 328: "Spanish-Moorish"!).

[33] Chicago, Ill., Adler Planetarium, inv. no. M-20—see Gunther, *Astrolabes*, I, p. 304 (no. 159: "Jewish Astrolabe"); Goldstein, "Hebrew Astrolabe"; and *Chicago AP Catalogue*, I, pp. 58-60 (no. 7: "Europe", "*c*. 1550"), where the quatrefoil is not even mentioned.

Fig. 4.1: Quatrefoil decoration on an astrolabe (#158) by a Jewish craftsman, probably in Bologna *ca*. 1400. The use of quatrefoils, regular and almost cruciform, is surely significant. [Courtesy of the British Museum, London.]

Fig. 4.2: A related astrolabe (#159) from the same milieu, but less carefully made. [Courtesy of the Adler Planetarium, Chicago, Ill.]

Fig. 5.1: al-Khujandī's quatrefoil had a good run in Europe as well as in the Islamic world. Here it is on an Italian astrolabe dated 1558 (#544), together with French-type star-pointers and a Renaissance Italian vertical bar. [Photo by the author, courtesy of the Special Collections, Columbia University Library, New York.]

Fig. 5.2: An unsigned astrolabe (#164) that can be attributed to Hans Dorn, Vienna, *ca*. 1480, previously classified as "Spanish". The unusual quatrefoil decoration dominates the rete design. See also **Fig. XIIb-10c-d** for another newly-discovered instrument by Hans Dorn. [Courtesy of the Adler Planetarium, Chicago, Ill.]
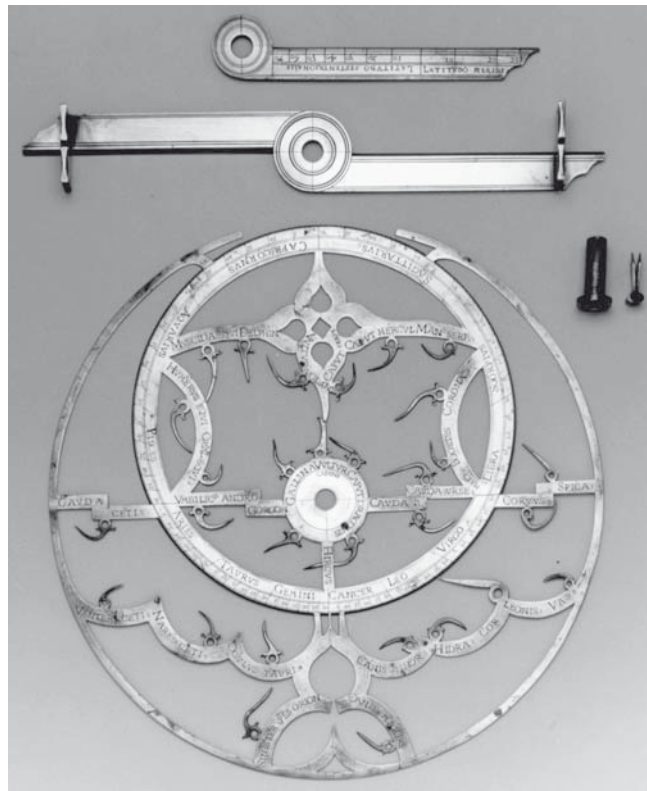
Fig. 5.3: The rete of an astrolabe by Georg Hartmann of Nuremberg dated 1541 (#4536). The design differs from that on his many standard astrolabes. One could argue that the design at the top of the rete, called "four-fold motif" in the 1995 Christie's catalogue, was developed from a quatrefoil. Certainly, the design at the bottom of the rete is a reworked half-quatrefoil. [Private collection; photo courtesy of the owner.]

#544 an astrolabe by the Italian craftsman, Bernadinus Sabeus, dated 1558.[34]

Or we may find ingenious extensions of the use of the quatrefoil, almost flippant and neo-gothic, such as on:

#164 an unsigned astrolabe to be associated with Hans Dorn of Vienna in the late 15th century (**Fig. 5.2**).[35]

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[34] New York, Columbia University Library, Special Collections, inv. no. 27-256 (13)—unpublished; rete illustrated in King, "Islamic Astronomical Instruments between East and West", p. 154.

[35] Chicago, Ill., Adler Planetarium, inv. no. M-28—see Gunther, *Astrolabes*, II, pp. 311-312 (no. 164: "Spanish *ca*. 1500"); and *Chicago AP Catalogue*, I, pp. 49-51 (no. 4: "Spain *c*. 1500?). In the former, Gunther appropriately mentions that "a central quatrefoil and three marginal semi-quatrefoils form a predominant feature of the design", but in the latter, all of the bits and pieces of quatrefoils are ignored.

The authority of the *mutaqaddimīn* amongst the *mutaʾakhkhirīn* is well illustrated by this incorrect attribution. Gunther had not seen any Dorn instruments, and specialists on the Vienna school would not need to look at any Spanish instruments. This particular astrolabe was actually displayed at the 1992 exhibition at the Jewish Museum in New York on the *convivencia* of Jews, Muslims and Christians in medieval Spain (see Glick, "Jewish Contribution to Science in Medieval Spain", fig. 21A on p. 88). On the other instruments of Hans Dorn see King & Turner, "Regiomontanus' Astrolabe", p. 188 and n. 52, and also *Washington NGA 1992 Exhibition Catalogue*, pp. 221-224 (nos. 120-122), on the three of his instruments preserved in Cracow.

Or we may find a quatrefoil in disguise, as on:
#4536 an astrolabe made in Nuremberg in 1541 by the prolific Georg Hartmann (**Fig. 5.3**).[36]

6 Other considerations

Only when I had assembled all of the photographic evidence for this study did I realize that there was another feature of the two main quatrefoils discussed in this study — that on the astrolabe of al-Khujandī and that on the Catalan astrolabe — which demands our attention.

In the former case, the centre of the quatrefoil divides the vertical between the centre of the astrolabe and the outer rim of the ecliptic scale in the "golden ratio", that is, *ca*. 5:3.[37] In the latter case, the same holds. However, in addition:

(1) the "rectangular" frame inside the upper ecliptic has been constructed with its upper side through the quatrefoil and extending to the inside of the ecliptic scale, and
(2) the vertical sides have been dropped down almost to the counter-changed horizontal bar, and then gracefully redirected with circular arcs down to the intersections of the inner ecliptic frame with that horizontal bar.

In other words, there is more to the positioning of the quatrefoils than I first thought. The fact that their positions are determined by what the Greeks called "the ratio", now called "the golden ratio", is surely highly significant and merits further investigation. In brief, I regard this as additional evidence—if any were needed—of an ultimate Byzantine origin of both of these basic rete designs.

7 Concluding remarks

Whilst the quatrefoil decoration on various medieval European astrolabes is typically "Gothic", the entire tradition of *quatrefoils on astrolabe retes* is probably Byzantine in ultimate origin and had a long afterlife in the Islamic East. The Hispano-Mauresque passion for quatrefoils resulted in some of the first Latin astrolabes in Spain having quatrefoil ornamentation (including the half-quatrefoils at the ends of horizontal or vertical axes). Various subgroups of the astrolabes of some regional schools in medieval Europe maintained this tradition and some developed it still further. When completely different designs appear in medieval Europe it is sometimes possible to trace those too to earlier Islamic designs.[38] And this is not to deny the initiative of medieval European craftsmen in the different regional schools of individual workshops, most of whose productions do not look anything like Islamic astrolabes.

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[36] Present location unknown—see the detailed and richly illustrated description in *Christie's London 02.03.1995 Catalogue*, pp. 36-41 (lot 199).

[37] On the golden ratio in recent literature see, for example, Herz-Fischler, *History of Division in Extreme and Mean Ratio* (book length monograph) and "The Golden Number" (brief summary); as well as Fischler, "On the Golden Number", and "The Golden Ratio in the Visual Arts"; and the bibliographies there cited.

[38] In King, "Urbino Astrolabe", I point to the similarities between the astrolabes of Abū Bakr ibn Yūsuf of Marrakesh, *ca*. 1200, and a medieval/Renaissance Italian tradition that subsequently influenced the Renaissance German tradition. Here the distinctive thrones provide the connection between the Maghribi and Italian pieces, with the rete design of the latter derived from the former by a kind of topological transformation. See now **Figs. XIIIa-10.4a-c** and **X-4.3.3**.

What the medieval and Renaissance European craftsmen saw in these quatrefoils is another issue. How little we can ever hope to understand their motives in including quatrefoils on astronomical instruments is clear from the medieval astrolabes with Hebrew inscriptions. Rather than look for Christian symbolism here, we may well ask what a Jewish craftsman saw in these quatrefoil decoration. These materials merit investigation by an art historian, but one cognisant of the Byzantine, Islamic, Hispano-Mauresque, Jewish, and medieval Christian traditions will be hard to find. And I have yet to meet an art historian who knows what an astrolabe actually is.

Part XVIII

A checklist of Islamic astronomical instruments to *ca*. 1500, ordered chronologically by region

To Kurt Maier, in appreciation

DEDICATION AND REMARKS ON THIS VERSION

This study is dedicated to the friend and colleague who was at my side whilst the research on which it is based was being started. It is hard to find words to express my gratitude to Kurt Maier for all his contributions over many years. Let me start with: "*Prosit tibi*!". For his mastery of languages (German, Schwäbisch, English, French, Italian, Catalan and Spanish, Latin, as well as Arabic and Persian), and his exactitude in scholarly writing (literary, historical and technical), I have only one word: "*Chapeau*!". For our pleasure and amazement when the computer generated this table of contents automatically from the text of the incomplete catalogue, there was only one appropriate exclamation: "*Mā shāʾ Allāh*!"

Had it not been for Kurt Maier, the medieval instrument project in Frankfurt might never have got off the ground. He was the mainstay of the project, writing letters in a multiplicity of languages to museums all over the world, and sharing the excitement when a new set of photos of some unpublished instrument eventually reached us; poring over photos for details that would establish the provenance of some undated piece; controlling inscriptions and deciphering Kufic or Gothic; searching for other attestations of linguistic rarities found on this instrument or that; ... . He came to have a special fascination for Islamic instruments bearing later European inscriptions by which one could document the subsequent fate of the piece concerned, and for inscriptions on medieval European instruments including regional varieties of Latin or European vernaculars by which one could establish the provenance. For the reader not familiar with the latest research, it should be mentioned that these methods had never been applied before to medieval instruments. See **Figs. 1-2** for two examples of later additions on an 11th-century astrolabe from Cordova on which he has worked. It was Kurt Maier, for example, who established the Picard provenance of the "Berselius astrolabe" (#198) and the Catalan origin of the "Spanish" astrolabe in the London Society of Antiquaries (#162).

1

2

Fig. 1-2: Medieval Catalan month-names and place-names added to an 11th-century astrolabe from al-Andalus (#3622). [Photos by the author, courtesy of the Jagiellonian University Museum, Cracow.]

I have already alluded (p. 5 in volume 1) to the fact that during the early 1990s Kurt Maier typed for me on a computer many texts that had been previously recorded on a typewriter in Cairo during the 1970s. Over several years, he controlled all of the texts that were generated relating to the instrument project, checking one version after the other of catalogue entries, and translating some of these texts into German when necessary. Thus it was he, for example, who is largely responsible for any merits the final versions of "Die Astrolabiensammlung im Germanischen Nationalmuseum" (1992) and "Astronomische Instrumente in Schweinfurt" (1993) may have. He also corrected various preliminary versions of my books *World-Maps Centred on Mecca* (1999) and *The Ciphers of the Monks* (2001), thereby saving me from many pitfalls. Alas, because of stupid university regulations that are in conflict with serious academic pursuits, he could not continue working at the Institute in an official capacity for more than five years. If he could have, there would certainly be fewer mistakes in these two volumes.

The following *bahnbrechende* publications have been contributed by Kurt Maier to our field:

- "Bemerkungen zu romanischen Monatsnamen auf mittelalterlichen Astrolabien", in *Ad radices—Festband zum fünfzigjährigen Bestehen des Instituts für Geschichte der Naturwissenschaften Frankfurt am Main*, Anton von Gotstedter, ed., Stuttgart: Franz Steiner, 1994, pp. 237-254.
- "Zeugen des Mehrsprachigkeit: mittelalterliche romanische Monatsnamen auf islamischen astronomischen Instrumenten", in *Romania arabica. Festschrift für Reinhold Kontzi zum 70. Geburtstag*, Jens Lüdtke, ed., Tübingen: Gunther Narr, 1996, pp. 251-270.
- "The Medieval Catalan Astrolabe of the Society of Antiquaries, London" (with David A. King), in *From Baghdad to Barcelona. Studies in the Islamic Exact Sciences in Honour of Prof. Juan Vernet*, Josep Casulleras and Julio Samsó, eds., 2 vols., Barcelona: Instituto "Millás Vallicrosa" de Historia de la Ciencia Árabe, 1996, II, pp. 673-718.
- "Ein islamisches Astrolab aus Córdoba mit späteren altkatalanischen Inschriften", in *Der Weg der Wahrheit—Aufsätze zur Einheit der Wissenschaftsgeschichte—Festgabe zum 60. Geburtstag von Walter G. Saltzer*, Peter Eisenhardt, Frank Linhard and Kaisar Petanides, eds., Hildesheim: Olms, 1999, pp. 119-133.

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Introductory remarks

> "On sait ... avec quel zèle les Arabes ont cultivé l'astronomie à une époque où cette science était complètement négligée, excepté dans les pays soumis à leur domination; nous avons un *assez grand nombre* des instruments dont ils se sont servis. On connaît plusieurs globes célestes arabes, un astrolabe arabe qui se trouve à Nuremberg; et il est présumable que nous aurons, par la suite, occasion d'en retrouver une plus grande quantité, lorsqu'on aura dirigé sur les antiquités l'attention des voyageurs et des Européens qui résident en Orient." Letter from Bernard Dorn to Louis-Amélie Sédillot (*fils*) (*ca*. 1840), published in his *Matériaux*, I, pp. 347-348.

> "A General Catalogue of the Astrolabes of the World has long been overdue. Many writers on the subject, being impressed by the scientific or unusual artistic excellence of some particular astrolabe and especially by the antiquity of the instrument have been inspired to learn its use and to publish an account of their single example: but it can have fallen to the lot of a few persons to have had the advantage of being able to examine as many astrolabes as the present author has had the good fortune of handling." Robert T. Gunther, *The Astrolabes of the World*, (1932), I, p. v.

In the past few years preliminary descriptions have been prepared in Frankfurt of a large number of medieval astronomical instruments.[1] The German Research Foundation generously provided funding during 1992-96 to prepare descriptions of all *Islamic* astronomical instruments to *ca*. 1550; a preliminary version was indeed achieved, but the state of photographic documentation of the instruments still leaves much to be desired and some of the descriptions remain incomplete. The same Foundation provided further funding during the period 1998-2001 to prepare descriptions of all medieval *European* instruments. The ultimate goal was to catalogue all available medieval instruments with "exhaustive" descriptions and photographic documentation, arranged chronologically according to geographical provenance, and based, as far as possible, on inspection of the instruments themselves. This is a long-term project, but already the majority, if not all, of the Islamic and European instruments from before 1500 have been inspected and described. It will still take some time to prepare the enormous corpus of descriptions for publication or projection into cyberspace. A major problem continues to be the assembling of a photographic archive, since even at the end of the 20th century many museums are incapable of producing publishable photographs and the prices of photographs are now out of sight. Another is that funding for the project is exhausted. And the same holds for the cataloguer.

The following list was generated automatically from the text of the Frankfurt catalogue. Unfortunately, the text of the catalogue does not look as good. I include the list here as a potential interim research tool, pending the imminent (?) publication of the long-awaited *Répertoire* of Alain Brieux and Francis Maddison and pending the appearance of the first sections of the Frankfurt catalogue beyond the earliest Islamic astrolabes included in this volume (**XIIIb-c**). I have also included some instruments later than *ca*. 1500 where these are under my control. The reader interested in globes is recommended to the survey by Emilie Savage-Smith; here I have only listed the earliest signed ones. For Safavid Iranian and Moghul

[1] Details are to be found in King, "Instrument Catalogue in Preparation", A-C.

Indian instruments, which I have not listed here, the reader must await the forthcoming publications of the late Alain Brieux and Francis Maddison, and Sreeramula R. Sarma, respectively. A more complete list of late Maghribi instruments, for what it is worth, is in my "Astronomy in the Medieval Maghrib", pp. 47-52.

The list from which the following one was taken has now been available for some years now on the Internet at www.uni-frankfurt.de/fb13/ign/instrument-catalogue.html, and there the reader will find listings of all medieval *European* instruments (not updated since *ca*. 1994). Although this was announced in various academic circles, including "RETE", the Oxford-based discussion group relating to historical instruments, only one colleague expressed any interest in it, namely, Tom Settle of City University, New York, who had a query about a Renaissance Italian piece. This well illustrates the problem anybody seriously interested in historical instruments has within the field of the history of science. And not a single voice from outside the field has been heard either.

More information on the very earliest European astrolabes is found in my "The Oldest European Astrolabe", pp. 387-391. Renaissance European instruments are now well served by the new publications of Koenraad van Cleempoel (16th-century Louvain and Spain) and Gerard L'E. Turner (Elizabethan England). For other regions the literature on Renaissance instruments is too scattered to collect here.

An asterisk in the list below indicates that an item has been moved from its position in the list available on the Internet. I have preferred to leave a few gaps than change the basic numbering.

List of abbreviations for present locations:

AG	Ahuan Gallery (London)
ALC	Alcázar de Córdoba (Cordova)
AM	Archaeological Museum (Baghdad / Damascus / Delhi)
AP	Adler Planetarium (Chicago)
BC	Biblioteca Communale (Palermo)
BM	The British Museum (London)
BM	Benaki Museum (Athens)
BNF	Bibliothèque nationale de France (Paris)
BNM	Bayerisches Nationalmuseum (Munich)
BTTM	Bilim ve Teknoloji ve Teknik Müzesi (Istanbul)
CBL	The Chester Beatty Library (Dublin)
CU	Columbia University Special Collections (New York)
DAI	Dār al-Āthar al-Islāmiyya (Kuwait)
DB	Dār Baṭhā᾽ (Fez)
DM	Deutsches Museum (Munich)
DM	Deniz Müzesi (Istanbul)
DMG	Deutsche Morgenländische Gesellschaft (Halle)
DS	Davids Samling (Copenhagen)
DSB	Deutsche Staatsbibliothek (Berlin)
EAS	Estonian Academy of Science (Tartu)
ENL	Eyptian National Library (Cairo)
GNM	Germanisches Nationalmuseum (Nuremberg)
GU	Galleria degli Uffizi, Gabinetto dei Disegni e Stampi (Florence)
HCSI	Harvard Collection of Scientific Instruments (Harvard, Ma.)
IGE	Instituto Geografico y Estadistico (Madrid)
IGN	Institut für Geschichte der Naturwissenschaften (Frankfurt)
IHAS	Institute for the History of Arabic Science (Aleppo)
IM	Indian Museum (Calcutta)
IMA	Institut du Monde Arabe (Paris)
IVDJ	Instituto de Valencia de Don Juan (Madrid)
JUM	Jagiellonian University Museum (Cracow)
KHM	Kunsthistorisches Museum (Vienna)
KO	Kasbah of the Oudaia (Rabat)
LC	Linton Collection (Point Lookout, Long Island)
MA	Musée archéologique (Fez / Tunis)
MA	Museo arqueológico (Almeria / Cordova / Granada / Madrid / Medina Azara / Sagunt)
MAH	Musée d'art et d'histoire (Geneva)
MAN	Museo Arqueológico Nacional (Madrid)
MB	Musée de Bouillon (Bouillon, B)
MC	Museo di Capodimonte (Naples)
MEC	Museo dell'Età Cristiana (Brescia)
MHS	Museum of the History of Science (Oxford)
MHS	Musée d'histoire des science (Geneva)
MIA	Museum of Islamic Art (Cairo)
MIB	Mūze-yi Īrān-i Bāstān (Tehran)
MIK	Museum für Islamische Kunst (Berlin)
ML	Musée du Louvre (Paris)
MMA	Metropolitan Museum of Art (New York)
MN	Musée nationale (Carthage)
MN	Museo Nazionale (Naples / Palermo)
MRAH	Musées royaux d'art et d'histoire (Brussels)
MN	Museo Navale (Venice)
MSQ	mosque, here not further identified
MSS	Museo di Storia della Scienza (Florence)
MVW	Musée de la vie wallone (Liège)
NG	Nur Gallery (Nasser D. Khalili Collection, London)
NMAH	National Museum of American History (Washington, D.C.)
NMM	National Maritime Museum (Greenwich)
NMM	National Maritime Museum (Haifa)
NSM	Nationaal Scheepvaartmuseum (Antwerp)
OBS	Observatory (Kandilli / Paris / Rome / Strasbourg)
OI	Oriental Institute (St. Petersburg)
MPD	Musée Paul Dupuy (Toulouse)
PC	Private collection
PLU	*present location unknown*
RACA	Real Academía de Ciencias y Artes (Barcelona)
RAH	Real Academía de la Historia (Madrid)
RKM	Rehmi Koç Müzesi (Istanbul)
ROM	Royal Ontario Museum (Toronto)
RSM	Royal Scottish Museums (Edinburgh)
SA	Society of Antiquaries (London)
SBOA	Staatsbibliothek Preußischer Kulturbesitz, Orientabteilung (Berlin)
SJL	Salar Jung Library (Hyderabad, Deccan)
SKS	Staatliche Kunstsammlungen (Kassel)
SL	State Library (Rampur)
SLMJ	Steirmärkishes Landesmuseum Johanneum (Graz)
SLSP	Società Ligure de Storia Patria (Genoa)
SM	Science Museum (London)
SMPS	Staatlicher mathematisch-physikalischer Salon (Dresden)
SS	Städtische Sammlungen (Kassel)
SSM	Statens Sjöhistoriska Museum (Stockholm)
TIEM	Türk ve İslām Eserleri Müzesi (Istanbul)
TM	Time Museum (Rockford, Ill.)
TM	Technisches Museum (Vienna)

TSM	Tokapı Sarayı Müzesi (Istanbul)
UK	Urdu College (Karachi)
VA	Victoria and Albert Museum (London)
WDB	West-Deutsche Bibliothek (Marburg), instruments now in DSB Berlin
WMHA	Whipple Museum for the History of Science (Cambridge)

1 Early Eastern astrolabes (to *ca*. 1500)

1 Byzantine astrolabes

1 An astrolabe by Sergios, "the Persian", dated 1062 (#2—Brescia MEC)
2 Miscellaneous bits and pieces
a) Markings on an Abbasid plate (#109 = #3549—New York MMA)
b) A single plate (#4509—PC)

2 The earliest Eastern Islamic astrolabes (9th to 11th C)

1 An early Abbasid astrolabe, modified in Ottoman times and bearing the name Aḥmad ibn Kamāl (#3702—Baghdad AM)
1* An early Abbasid astrolabe, badly corroded (#4020—London AG) [MOVED FROM FORMER 1.2.14]
2 Two instruments by (Muḥammad ibn ʿAbdallāh known as) Nasṭūlus
a) An astrolabe dated 315 H (#3501—Kuwait DAI)
b) An undated mater (#4023—Cairo MIA)
3 Three instruments by Khafīf
a) An undated astrolabe (#1026—Oxford MHS)
b) A solitary rete (#2529—Oxford MHS)
c) An undated astrolabe illustrated in a set of 16th-century Italian drawings (#4030—Florence GU)
4 An astrolabe by Aḥmad ibn Khalaf (#99—Paris BNF)
5 An undated astrolabe by Muḥammad ibn Shaddād (al-Baladī) (#1179—PLU, formerly Berlin PC)
6 An undated astrolabe by al-Muḥsin ibn Muḥammad al-Ṭabīb (#4030—Rockford TM)
7 The so-called "Astrolabe of Pope Sylvester II": an unsigned undated Abbasid astrolabe with later (19th-century?) additions by a European (#101—Florence MSS)
8 An unsigned mater and plates (#4022—London SM)
9 Two instruments by Ḥāmid ibn ʿAlī (al-Wāsiṭī)
a) A mater dated 343 H (#100—Palermo MN—stolen ?)
b) An undated mater (#3713—Cairo MFI)
10 An astrolabe by Ḥāmid ibn Khiḍr al-Khujandī (#111—Kuwait PC)
11 An astrolabe by Aḥmad and Muḥammad, sons of Ibrāhīm al-Iṣfahānī, dated 374 H (#3—Oxford MHS)
12 An astrolabe by Muḥammad ibn Abi 'l-Qāsim al-Iṣfahānī al-Ṣāliḥānī dated 496 H (#122—Florence MSS)
13 A solitary plate with ogival markings (#4021—Copenhagen DS)
14 [MOVED TO 1.2.1*]
14* Miscellaneous bits and pieces
a) A solitary rete (#2529—Oxford MHS)
b) A solitary plate (#109 = #3549—New York MMA)
c) The rete and plate of an unsigned astrolabe (#4022—London SM)

d) The rete on the Cairo astrolabe of Ḥāmid ibn ʿAlī (#3713—Cairo MIA)
e) A single plate (#1026—Oxford MHS)

3 The earliest Western Islamic astrolabes (10th and 11th centuries)

1 An astrolabe by Khalaf ibn al-Muʿādh illustrated in a Latin manuscript (#4024—manuscript in Paris BNF)
2 An unsigned, undated astrolabe (#110—London BM)
3 Some instruments by Muḥammad ibn al-Ṣaffār
   a) A mater and plates dated 417 H (#3650—Edinburgh RSM)
   b) An astrolabe dated 420 H (#116—Berlin DSB, formerly Marburg WDB)
   c) A solitary plate (#4025—Palermo MN)
4 Two instruments by Ibrāhīm ibn ʿAbd al-Karīm
   a) A mater dated 458 H (#3714—Fez MA)
   b) An undated astrolabe (#1079—Palermo MN—stolen)
5 Three astrolabes by Ibrāhīm ibn Saʿīd ibn Aṣbagh al-Anṣārī *thumma* al-Sahlī al-Mawāzīnī
   a) Dated 4b59 H (#117—Madrid MAN)
   b) Dated 460 H (#118—Oxford MHS)
   c) Dated 463 H (#123 = #1167—Rome OBS)
6 An astrolabe by Ibrāhīm ibn al-Sahlī dated 478 H (#121—Kassel SS)
7 Two astrolabes by Muḥammad ibn Saʿīd al-Ṣabbān
   a) Dated 466 H (#1139—Munich BNM)
   b) Dated 474 H (#2527—Oxford MHS)
8 An astrolabe by Muḥammad ibn al-Sahlī dated 483 H (#2572—Washington NMAH)
9 An astrolabe by Aḥmad ibn Muḥammad al-Naqqāsh dated 472 H (#1099—Nuremberg GNM)
10 An unsigned Andalusī astrolabe dated 446 H (#3622—Cracow JM)
11 Miscellaneous bits and pieces
   a) Some 11th-C Andalusī plates in a composite Ottoman astrolabe (#4040—PC)
   b) The rete on the Edinburgh astrolabe of Muḥammad ibn al-Ṣaffār (#3650—Edinburgh RSM)
   c) A single plate (#2572—Washington NMAH)
   d) An isolated plate (#4025—Palermo MN)
   e) A single plate (#154—Chicago AP)

4 Later Eastern Islamic astrolabes (Iraq and Iran, 12th to 16th C, also Turkey, 16th C)

1 An "astrolabic *zīj*" by Hibatallāh dated 514 H (#3633—formerly Munich PC, now Berlin MIK)
2 An astrolabe in the tradition of al-Khujandī by Badr (ibn ʿAbdallāh), *mawlā* of Hibatallāh, dated 525 H (#2557—Chicago AP)
3 [MOVED TO 1.5.17a]
4 An astrolabe by Ḥāmid ibn Maḥmūd al-Iṣfahānī dated 547 H (#4—Point Lookout LC)

5 Four astrolabes by Muḥammad ibn Ḥāmid ibn Maḥmūd al-Iṣfahānī
   a) Dated 556 H (#1177—Istanbul TIEM)
   b) Dated 558 H (#1211—Tehran MIB)
   c) Dated 571 H (#4199—Kuwait DAI)
   d) Undated (#3532—London AG)
6 An astrolabe by Muḥammad ibn Aḥmad ibn ʿAlī ibn Muḥammad dated 588 H, reworked by Muḥammad Khalīl in 1110 H (#3922—Frankfurt IGN)
7 Two instruments by Muḥammad ibn Abī Bakr al-Rāshidī al-Ibarī al-Iṣfahānī
   a) An astrolabe with gear mechanism dated 618 H (#5—Oxford MHS)
   b) A rete and plate (#4031—London NG)
8 An astrolabe by Maḥmūd ibn ʿAlī ibn Yūshaʿ *al-...x-r-y* dated 669 H ("Prof. Wilson's astrolabe") (#67—PLU)
8* An astrolabe mater by Maḥmūd ibn ʿAlī al-Ṭabarī dated 675 H (#3657—PLU): see **Fig. 3**
9 An unsigned mater and plates with a later Ottoman rete (#2537—Oxford MHS)

Fig. 3: The signature on the astrolabe mater of Maḥmūd ibn ʿAlī al-Ṭabarī dated 675 H [= 1276/77] (#3657) on the lower left rim. The letters *sīn-nūn* at the end of the signature after the date defy explanation. Likewise the minister for whom the piece was made remains unidentified. The orthography of the divine name in the third line of the dedication is most unexpected. The front of the mater bears astrological markings. [Present location unknown; photo from the archives of Alain Brieux, courtesy of Dominique Brieux.]

10 Three instruments by Maḥmūd ibn Shawka al-Baghdādī
- a) A mater and plates dated 684 H (#4101—Kandilli OBS)
- b) An astrolabe dated 694 H (#1040—Greenwich NMM)
- c) A mater dated 706 H (#3534—Paris IMA—for the rete and plates see 2.3.6)

11 An astrolabic plate by ʿUmar ibn Dawlatshāh al-Kirmānī dated 726 H (#4033—Point Lookout LC)

12 Some instruments by Jaʿfar ibn ʿUmar al-Kirmānī
- a) An astrolabe dated 751 H (#3660—Paris PC)
- b) A mater dated 755 H (#1205—Paris IMA)
- c) An astrolabe dated 774 H (#15—Washington NMAH)
- d) An astrolabe dated 790 H (#16—Calcutta IM)
- e) A mater dated 790 H (#2605—Chicago AP)
- f) A fake astrolabe dated 757 H (#1033—Greenwich NMM)

13 Some instruments by Muḥammad ibn Jaʿfar ibn ʿUmar al-Kirmānī known as Jalāl
- a) An astrolabe dated 796 H (#2710—Fez MA)
- b) The rete and plates on the first astrolabe of ʿAbd al-Karīm al-Miṣrī (#7 < #103—Oxford MHS—see 1.5.4a for the mater)
- c) An astrolabe dated 830 H and dedicated to [Ulugh Beg] (#3595—Copenhagen DS)
- d) An astrolabe mater dated 832 H (#4305—PLU)
- e) A single plate (#4151—Istanbul TIEM)

14 Three instruments by Maḥmūd ibn Jalāl al-Kirmānī
- a)* An astrolabe dated 833 H (#4307—PC) [NEW]
- b) An astrolabe dated 838 H (#4034—Chicago PC)
- c) A mater and plates dated 849 H (#1168—Istanbul TIEM)

15-15 Two astrolabes dedicated to the Ottoman Sultan Bāyazīd II*

15 An astrolabe by Mukhliṣ Shirwānī dated 910 H (#12—Cairo MIA)

15* An astrolabe by al-Aḥmar al-Nujūmī al-Rūmī dated 892 H (#4183—PLU) [NEW]

16 An astrolabe by Aḥmad ibn Ḥasan al-Ḥusaynī dated 891 H (#4102—Kandilli OBS)

17 Five instruments by Shams al-Dīn Muḥammad Ṣaffār
- a) A mater and plates dated 878 H (#1063—Brussels MRAH)
- b) An astrolabe dated 882 H (#1186—Cambridge WMHS)
- c) An astrolabe dated 882 H (#1136—Cairo MIA)
- d) An astrolabe dated 886 H (#108—Oxford MHS)
- e) An astrolabe dated 911 H (#2505—Oxford MHS)

18 Two astrolabes in the tradition of Shams al-Dīn Ṣaffār
- a) An astrolabe in the tradition of al-Khujandī signed by Muḥammad ibn Khiḍr al-Aṣṭurlābī and dated "667 H" (#4035—London AG)
- b) An unsigned astrolabe with qibla markings on the back (#30—Oxford MHS)

19 Two astrolabes by Awḥad al-Awḥadī
- a) Dated 890 H (#112—London BM)
- b) Dated 902 H (#4156—Haifa NMM)

5 Ayyubid, Mamluk and Rasulid astrolabes (Syria, Egypt and the Yemen, 13th to 14th C)

1* An astrolabe with a rete decorated with circus figures by al-Sahl al-Nīsābūrī (#137—Nuremberg GNM) [MOVED FROM 1.5.10]

1 Two related *ṣafīḥa*s
  a) An undated *ṣafīḥa zarqālliyya* by ʿAlī al-Wadāʿī (#4026—Rockford TM)
  b) An early copy (#4027—London AG)

2 An astrolabe by ʿAbd al-Raḥmān ibn Sinān al-Baʿlabakkī dated 619 H (#4050—Istanbul DM)

3 Two astrolabes by al-Sarrāj of Damascus
  a)* Dated 623 H (#4160—Hyderabad SJL) [NEW]
  b) Dated 626 H (#3765—Rampur SL)
  c) Dated 628 H (#1042—Greenwich NMM)

4 Two instruments by ʿAbd al-Karīm al-Miṣrī
  a) A mater dated 625 H (#103—Oxford MHS; for the rete and plates see 1.4.13b)
  b) An astrolabe dated 638 H (#104—London BM)

5 An unsigned Ayyubid astrolabe from Egypt (#105—London BM)

6 A *ṣafīḥa shakkāziyya* by Ibrāhīm al-Dimashqī dated 669 H (#106—London BM)

7-8 Two instruments with inscriptions in both Arabic and Coptic

7 An astrolabe with Arabic and Coptic inscriptions by Ḥasan ibn ʿUmar al-Naqqāsh dated 681 H (#4036—Istanbul TIEM)

8 An instrument with Arabic and Coptic inscriptions by Ḥasan ibn ʿAlī dated 681 H (#107—Oxford MHS)

9 An unsigned Egyptian astrolabe with unusual features including a Maghribi-style rete and a *shakkāziyya*-type projection for [Cairo] (#134—Delhi AM)

10 [MOVED TO 1.5.1*]

11 Two *ṣafīḥa*s by ʿAbdallāh ibn Yūsuf
  a) A *ṣafīḥa shakkāziyya* dated 693 H (#4028—Kuwait PC—stolen)
  b) A *ṣafīḥa zarqālliyya* dated 695 H (#102—London VA)

12 Some astrolabes by the Yemeni Sultan al-Ashraf
  a) Dated 690 H (#109 = #3549—New York MMA)
  b) Some other astrolabes mentioned by his teachers

13 An unsigned, undated Rasulid astrolabe (#4029—Paris IMA)

13* An unsigned, undated Yemeni astrolabe with a Maghribi rete (#4170—Cambridge, Ma., HCSI)

14 Two instruments by Aḥmad ibn Abī Bakr ibn al-Sarrāj
  a) A quintuply-universal astrolabe dated 729 H (#140—Athens BM)
  b) An unsigned mater from a standard astrolabe (#4037—London NG)

15 An unsigned astrolabic plate for multiple latitudes (#4038—Berlin DSB, formerly Marburg WDB)

16 An astrolabe plate by Muḥammad ibn Aḥmad al-Mizzī dated 734 H (#1204—Cambridge WMHS)

16* An undated astrolabe copied from one by al-Mizzī (#4164—Cairo MIA)

17 Three instruments by ʿAlī ibn Ibrāhīm known as Ibn al-Shāṭir
   a)* An astrolabe dated 726 H (#6—Paris OBS) [MOVED FROM 1.4.3]
   b) An astrolabic plate dated 733 H (#1131—Cairo MIA)
   c) An astrolabic plate dated 733 H (#142—Paris BNF)

6 Later Andalusī and Maghribi astrolabes (13th to 16th C)

1 Seven astrolabes by Abū Bakr ibn Yūsuf
   a) A universal astrolabe in the tradition of ʿAlī ibn Khalaf dated 584 H mentioned in a medieval text (#4039—manuscript in Cairo ENL)
   b) An astrolabe dated 605 H (#124—Strasbourg OBS)
   c) An astrolabe dated 610 H (?) (#2709—Rabat KO)
   d) An astrolabe dated 613 H (#1090—Toulouse MPD)
   e) An astrolabe dated 615 H (#125—PLU, formerly Baron de Larrey)
   f) An astrolabe reworked by a European with maker's name and date obliterated (#1069—Madrid IVDJ)
   g) A rete and set of plates (#1057—London SM)
2 Fourteen astrolabes and *ṣafīḥa*s by Muḥammad ibn Fattūḥ al-Khamāʾirī of Seville dated between 609 H and 634 H
   a) A mater dated 609 H (#127—PLU)
   b) A *ṣafīḥa* dated 613 H (#1081—Rome OBS—stolen)
   c) An astrolabe dated 614 H (#2701—Fez DB)
   d) A *ṣafīḥa* dated 615 H (#128—Paris BNF)
   e) An astrolabe (??) dated 615 H (#1147—PLU, formerly Cairo PC)
   f) An astrolabe dated 618 H (#4053—Istanbul BTTM)
   g) An astrolabe dated 618 H (#129—Oxford MHS)
   h) A mater and plates dated 619 H with a replacement rete from the Arsenius workshop (#4054—PC)
   i) An astrolabe dated 620 H (#4052—Istanbul TIEM)
   j) A mater and plates dated 621 H (#4001—Washington NMAH)
   k) An astrolabe dated 621 H (#130—Oxford MHS)
   l) An astrolabe dated 628 H (#1148—Cairo MIA)
   m) An astrolabe dated 634 H (#150 = #153—Chicago AP)
   n) An undated mater (#4148—PLU)
2* An astrolabe by Muḥammad ibn ʿAbd al-ʿAzīz al-Khamāʾirī dated 624 H (#4299—PLU) [NEW]
3 An astrolabe by Muḥammad ibn Yūsuf ibn Ḥātim dated 638 H (#154—Chicago AP)
4 A *ṣafīḥa zarqālliyya* by Muḥammad ibn Muḥammad ibn Hudhayl dated 650 H (#1071—Barcelona RACA)
5 An astrolabe by ʿUthmān ibn ʿAbdallāh al-Ṣaffār dated 699 H (#1077—Florence MSS)
6 Three astrolabes by Aḥmad ibn Ḥusayn ibn Bāṣo and a related unsigned piece
   a) Dated 694 H (#132—Madrid RAH)
   b) Dated 704 H (#144—Point Lookout LC)

c) Dated 709 H (#1203—PC)
d) An unsigned, undated astrolabe (#1100—Vienna TM)

7 An astrolabe by al-Ḥusayn ibn ʿAlī dated 709 H(#1204—Cambridge WMHS)

8 An astrolabe by Ibrāhīm ibn Muḥammad ibn al-Raqqām (#136—Madrid RAH)

9 A mater and a universal myrtle astrolabe by ʿAlī ibn Ibrāhīm al-Jazzār
a) A mater dated 724 H (#4041—Geneva MHS)
b) A universal myrtle astrolabe dated 728 H (#3579—Oxford MHS)

10 An astrolabe by Aḥmad ibn Muḥammad ibn Hārūn al-Ḥadabī dated 728 H (#1121—Fez DB)

11 An astrolabe by Aḥmad ibn ʿAlī al-Sharafī dated 729 H (#1161—Stockholm SSM)

12 The astrolabic clock of Fez, first made by Abū ʿAbdallāh Muḥammad al-Ḥabbāk al-Tilimsānī in 685 H (#4042 — Fez MSQ)

13 An unsigned astrolabe in the tradition of Abū Bakr ibn Yūsuf dated 779 H (#1061—Rome OBS—stolen)

14 Three unsigned instruments in the tradition of al-Khamāʾirī
a) An astrolabe for Seville (#3551—Naples MC)
b) A rete and a plate (#3901—Venice MN)
c) An astrolabe dated 785 H (#4043—Damascus AM)

15 Some unsigned, undated astrolabes in the tradition of al-Khamāʾirī
a-b) Two astrolabes with a *ṣafīḥa shakkāziyya* on the back
a) (#4044—Rockford TM)
b) (#139—Oxford MHS)
c) "Marcel's Egyptian astrolabe" (#1160—PLU)
d) (#4045—Bouillon MB)
e) A late-13th-C unsigned Andalusī / Maghribi astrolabe—"The Imola Astrolabe" (#4184—Bologna)
f) "Dr. Knuthsen's astrolabe" (#3640—PLU)
g) With a replacement throne and Eastern Islamic rete (#3643—Washington NMAH)
h) An unsigned Maghribi astrolabe, *ca*. 1600 (#40476—Geneva MAH)
i) (#3601 or #3602—Haifa NMM)
j) (#4047—Point Lookout LC)
k) (#4048—Halle DMG)
l) John Selden's Maghribi astrolabe (#149—Oxford MHS)
m) (#1001—Oxford MHS)
n) (#1067—Madrid MAN)
o) (#1066—Madrid MAN)
p) (#151 = #1080—Genoa SLSP)
q) (#4310—PC)
r) An astrolabe with eight plates serving latitudes from the Yemen to Provence (#4051—Istanbul DM)
s*) An astrolabic plate for latitude 34° with a simplified rete and cotangent tables on the back (#5027—London VA)

16 Three other undated, unsigned astrolabes not in the tradition of al-Khamāʾirī
 a) With a *shakkāziyya* grid on the back (#1078—Florence MSS)
 b) An astrolabe with a "counter-ecliptic" frame on the rete (#1068—Madrid IVDJ)
 c) "Dorn's Aleppo astrolabe" (#126—PLU)
17 An astrolabe by Muḥammad ibn Faraj of Granada dated 881 H (#3552—Naples MC)
17* An astrolabe made by Muḥammad ibn Zawāl (??) in Granada in 886 H (#4217—Granada MA)
18 An astrolabe by Aḥmad ibn ʿUmar al-Kabbī dated 933 H (#1188—Cambridge WMHS)
19 An astrolabe by ʿAlī and Muḥammad al-Azdī dated 950 H ("The Valdagno Astrolabe") (#148—Rome OBS—stolen)
20 An astrolabe (??) / or two astrolabes (??) by ʿAlī ibn Muḥammad ibn ʿAbdallāh ibn Faraj
 a) Dated 910 or 1010 H (#2571—Washington NMAH)
 b) Dated 910 or 1010 H (#1178—Karachi UC)
21 An astrolabe by Yaʿqūb ibn Mūsā Tapiero supposedly dated 716 H (but more probably 1016 H) (#1122—Morocco PC)
22 Miscellaneous bits and pieces
 a) A single plate (#154—Chicago AP)

2 Late Eastern astrolabes (16th to 19th C)

1 Late Eastern Islamic astrolabes in the early tradition (16th to 19th C)

1 A degenerate astrolabe signed by Ḥusayn ibn *B-k-s* (?) al-Raḥāqī in 913 H and displaying some unusual features (#4131—PLU, London Christie's 1991)
2 Two astrolabes bearing the signature of Yūsuf ibn Ḥājjī al-Jīlānī
 a) An astrolabe dated 929 H (#1031—Greenwich NMM)
 b) A fake astrolabe dated 927 H (#1030—Greenwich NMM)
3 A composite astrolabe with a European mater and a set of plates and rete from al-ʿIrāq or Iran (#4130—Palermo BC)
4 An anomalous astrolabe in the tradition of al-Khujandī by Wafāʾ-yi Munajjim and dated 1017 H (#2708—Point Lookout LC)
5 A similar, degenerate astrolabe signed by *Ḥ-x-x* (?) ibn *al-ʿ-f-w* (?) (#4132—Washington SB)
6 An astrolabe by Riḍā Khalīl Bannāʾ dated 1067 H (#2567—Washington NMAH)
7 An unsigned astrolabe dated 1202 H (#57—Washington NMAH)
8 Miscellaneous bits and pieces

2 Late Egyptian and Syrian astrolabes (17th to 19th C)

1 An astrolabe by ʿAlī Beg dedicated to al-Qāḍī Walī al-Maḥmūdī al-Ruhāwī and dated 1040 or 1104 H (#4125—Istanbul PC)
2 A late, unsigned Egyptian astrolabe (#1065—Antwerp NSM)
3 An unusual astrolabic plate for [Damietta] (#4133—Greenwich NMM)

4 An astrolabe of the "Fusoris"-type reworked by a Syrian or Egyptian in the 19th C (#460—Antwerp NSM)

3 Some late Ottoman Turkish astrolabes (17th to 19th C)

1 Two astrolabes by ʿAlī ibn ʿIwaḍ al-Maḥmūdī
   a) Dated 1006 H (#3705—Kandilli OBS)
   b) Dated 1020 H (#70—Washington NMAH)
2 Two unsigned, dated instruments
   a) A mater and plate dated 1062 H (#4206—Paris IMA)
   b) An astrolabe dated 1089 H (#28—Oxford MHS)
3 An astrolabe by ʿAlī al-Zaʿtarī dated 1082 H (#3712—Kandilli OBS)
4 A replacement rete and two plates for an astrolabe by Adrian Descrolières (#4104—Kandilli OBS)
5 Two astrolabes and some replacement parts by Ibrāhīm ibn Muḥammad al-Balawī
   a) An astrolabe dated 1097 H (#3539 = #3805—Paris IMA)
   b) A replacement rete and plate dated 1098 H for an astrolabe by Maḥmūd ibn Shawka al-Baghdādī (#4101—Kandilli OBS)
   c) An astrolabe dated 1099 H (#4108—Kandilli OBS)
6 A replacement rete and plates by Aḥmad Ayyūbī dated 1097 H made for a mater by Maḥmūd ibn Shawka al-Baghdādī (#3533—Paris IMA—see 1.4.10e for the mater)
7 Three or four (?) astrolabes by Muṣṭafā Ayyūbī
   a) Dated 1110 H (#1218—Paris PC = b ?)
   b) Dated 1110 H (#4155—PLU = a ?)
   c) Dated 1114 H (#1059—London SM)
   d) Dated 1115 H (#3541—Paris IMA)
8 An astrolabe by Ibrāhīm al-Muftī dated 1120 H (#1064—Liège MVW)
9 An astrolabe by ʿAbdī dated 1125 H (#1222—Oxford MHS)
10 Two instruments by the same maker
   a) A mater and rete and some plates to accommodate a set of 11th-C Andalusī plates (#4040—PC)
   b) (#4112—Kandilli OBS)
11 Some late, undated, signed astrolabes
   a) Muqīm Zāde (#4110—Kandilli OBS)
   b) "Yūsuf" (#4151—Istanbul TIEM)
12 Some late, unsigned, undated astrolabes
   a) (#4152—Haifa NMM)
   b) (#4114—Kandilli OBS)
   c) (#4113—Kandilli OBS)
   d) (#4111—Kandilli OBS)
13 Two unsigned and undated astrolabes made out of wood and cardboard
   a) An astrolabe (#4153—London AG)
   b) A rete and set of plates (#4154—London AG)

14 Miscellaneous bits and pieces
- a) An unsigned, undated mater (#4115—Kandilli OBS)
- b) A rete (#2537—Oxford MHS)
- c) The rete on the astrolabe of al-Ḥusayn ibn ʿAlī (#1204—Cambridge WMHS)
- d) Two plates on an astrolabe by Ibn Bāṣo (#144—Point Lookout LC)
- e) Three plates on a Western Islamic astrolabe (#139—Oxford MHS)
- f) Two replacement plates on an astrolabe by ʿAbd al-Raḥmān ibn Sinān al-Baʿlabakkī (#4050—Istanbul DM)
- g) An additional plate on an unsigned Maghribi astrolabe (#4051—Istanbul DM)

4 Late Maghribi astrolabes (17th to 19th C)

1 Three astrolabes by al-Ḥasan ibn Aḥmad al-Baṭṭūṭī
- a) Dated 1097 H (#2707—Point Lookout LC)
- b) Dated 1103 H (#2568—Washington NMAH)
- c) Dated 1106 H (#3804—Cairo MIA)

2 Some astrolabes by Muḥammad ibn Aḥmad al-Baṭṭūṭī
- a) Dated 1128 H (#3663—Point Lookout LC)
- b) Dated 1134 H (#1041—Greenwich NMM)
- c) Dated 1136 H (#1062—PLU)
- d) Dated 1146 H (#1023—Oxford MHS)
- e) Dated 1151 H (#1027—Greenwich NMM)
- f) Undated (#1024—Oxford MHS)

3 An anonymous Maghribi astrolabe with a transversal alidade (#4049—London SM)

4 Two astrolabes by Sharaf Allāh
- a) Undated and dedicated to the Sharīf Muḥammad ibn ʿAbdallāh (#3544—Paris IMA)
- b) Unsigned and dated 1179 H (#1070—Madrid IGE)

5 Some late, signed and dated Maghribi astrolabes
- a) An astrolabe by ʿAbdallāh ibn Sāsī dated 1099 H (#145—Oxford MHS)
- b) An astrolabe by Muḥammad ibn Aḥmad ibn Ibrāhīm of Fez, dated 1104 H (#3709—PLU)
- c) An astrolabe by Aḥmad ibn Muḥammad ibn Ibrāhīm of Fez dated 1116 H (#1162—PLU)
- d) An astrolabe by Aḥmad ibn Ibrāhīm al-Jazzār (?) (#3547—Tunis MA)
- e) An astrolabe by Qāsim ibn ʿAbd al-Salām al-Tamlī in 1192 H (#1180—Tetuan ??)
- f) An astrolabe by Muḥammad ibn ʿAlī al-Ghazāwī dated 1314 H (#1181—PLU)

6 Three astrolabes by Muḥammad ibn al-Mufaḍḍal ibn Aḥmad ibn Kīrān
- a) Dated 1126 H (#3918—Rockford TM)
- b) Dated 1264 H (#4134—Chicago AP)
- c) Unsigned and undated (#155—Oxford MHS)

7 Some late, unsigned Maghribi astrolabes

5-7 Selected Indo-Persian astrolabes (16th to 19th C)

5 Some astrolabes of the Safavid schools (16th to 18th C)

Note: No instruments are listed here, though see King, *Mecca-Centred World-Maps*, pp. 263-264, *etc*. The forthcoming *Répertoire* of Brieux & Maddison promises to be the most reliable source on these.

6 Some astrolabes of the Lahore school (16th to 17th centuries)

Note: I have not included any instruments other than the three earliest ones and the recently recovered universal astrolabe. The forthcoming survey by S. R. Sarma (see the preamble to **XIVf)** promises to be the most reliable reference work on these.

1* An astrolabe by [Maqṣūd Harawī] datable to the mid 16th C (#4301—London NG)

1 Two astrolabes by Allāh-dād
   a) Dated 975 H (#1120—Hyderabad SJM)
   b) Undated (#1089—Oxford MHS)

• A universal astrolabe attributable to Jamāl al-Dīn ibn Muḥammad Muqīm Lāhūrī (#4201—London AG)

7 Miscellaneous Indo-Persian astrolabes (17th to 19th C)

Note: No instruments included here.

3 Eastern quadrants

1 Early Eastern Islamic quadrants

1 An horary quadrant for [Nishapur or the 4th climate] by Muḥammad ibn Maḥmūd (al-Ṭabarī) (#5001—New York MMA)

2 Sine quadrants on early Islamic astrolabes

3 Universal horary quadrants on early Islamic astrolabes

4 Horary quadrants for specific latitudes on early Islamic astrolabes

2 Egyptian and Syrian quadrants (Mamluk and early Ottoman periods)

1 An horary quadrant for [Cairo] by Saʿdū ibn ʿAlī al-Muʾadhdhin (#5002—Kuwait PC—stolen)

2 Five astrolabic quadrants by Shams al-Dīn Muḥammad ibn Aḥmad al-Mizzī
   a) Dated 727 H (#5003—London BM)
   b) Dated 727 H (#5004—Cairo MIA)
   c) Dated 730 H (#5005—Copenhagen DS)
   d) Dated 734 H (#141 = #5006—St. Petersburg OI)
   e) Dated 734 H (#5007—London BM)

3 An astrolabic quadrant by ʿAlī ibn al-Shihāb dated 735 H (#5008—London BM)

4 Two astrolabic quadrants by Abū Ṭāhir
  a) Dated 741 H (#5009—Athens BM)
  b) Date illegible (#5010—Dublin CBL)
5 An unsigned astrolabic quadrant for [Damascus] (#5011—Greenwich NMM)
5* An astrolabic quadrant for Aleppo by Shams al-Dīn ibn Ghars al-Dīn al-Ḥalabī dated 967 H (#5145—London Sotheby's 2005)
6 An astrolabic quadrant for Damascus by Muḥammad al-Ṣakāsī al-Jirkisī dated 1307 (#5012—London BM)
7 Some late quadrants
  a) An astrolabic quadrant for [Damascus] (#5013—London SM)
  b) An astrolabic and sine quadrant for Cairo by Muḥammad Abi ʻl-Faḍl al-Falakī (#5014—Cairo ENL)
  c) For [Damascus] by ʿAbd al-Muḥsin ibn Ṣāliḥ Efendī al-Murādī, dated 1297 H (#5015—London NG)

3 Maghribi quadrants

1 An astrolabic quadrant for [Tunis] by Aḥmad ibn ʿAbd al-Raḥmān al-Dahmānī, dated 854 H (#5021—Madrid MAN)
2 An unusual quadrant for [Marrakesh] (#5022—Chicago AP)

4 Ottoman quadrants

Note: Only some of the most remarkable are listed here.

5 Some unusual signed Ottoman quadrants
  a) A quadrant with crescent astrolabic and winged markings on one side and a "complete" trigonometric grid on the other by ʿArab Zāde ʿĀrif, dated 1117 H (#5151—Cairo ENL)
  b) An winged quadrant and multiple horary quadrant by Shukr Zāde, dated 1178 H (#5152—Cairo ENL)
  c) A double horary quadrant for latitude [41°] by ʿAlī, dated 1211 H (#5153—Cairo ENL)
  d) An astrolabic quadrant for latitude 37° by Dūdī (?) and an incomplete multiple horary quadrant by (?) ʿUthmān Busnawī (#5154—PLU)
6 Some unusual unsigned Ottoman quadrants
  a) An astrolabic projection + two octants (#5155—Cairo ENL)

4 Eastern sundials

Anthony Turner has prepared a list of some 50 signed Islamic sundials to include in his forthcoming history of sundials. This adds to those listed below numerous late pieces, mainly featured in Brieux & Maddison, *Répertoire*, which is not available to me.

1 Sundials from the Islamic East

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2 Andalusī sundials

Note: On these see King, “Three Andalusī Sundials”; and Labarta & Barceló, “Un nuevo fragmento de reloj de sol andalusí”, and “Ocho relojes de sol hispanomusulmanes”; and King, “Cuadrantes solares andalusíes”.

1 A sundial by Ibn al-Ṣaffār (#7301—Cordova MA)
2 Six unsigned Andalusī sundials, all now fragmentary
 a) With markings for the zodiacal signs (#7302—Cordova ALC)
 b) (#7303—Almeria MA)
 c) (#7304—Cordova MA)
 d) (#7305—Cordova MA)
 e) (#7306—Cordova MA)
 f) (#7307—Sagunt MA)
 g) (#7308, *etc*.—Medinat Azara MA)
3 A degenerate sundial (#7308—Granada MA)

3 Ayyubid and Mamluk sundials

1 A vertical sundial by Abu l-Faraj ʿĪsā dated 554 H (#7315—Paris BNF)
2 An unsigned sundial for the Mosque of Ibn Ṭulūn in Cairo, dated 696 H (#7316—destroyed)
3 A sundial for Cairo by Khalīl ibn Ramtāsh dated 726 H (#7317—London VA)
4 A sundial for the main minaret of the Umayyad Mosque in Damascus made by ʿAlī ibn Ibrāhīm ibn Muḥammad al-Anṣārī (known as Ibn al-Shāṭir) in 773 H (#7318—Damascus AM) and a copy thereof by Muḥammad ibn Muṣṭafā al-Ṭanṭāwī in 1293 H (#7319—Damascus MSQ)
5 A sundial by Aḥmad al-Ḥarīrī dated 785 H (#7320—Cairo MSQ)
6 An unsigned, undated Mamluk vertical sundial (#7321—Jerusalem MSQ)

4 Maghribi sundials

1 A sundial for Tunis by Abu ’l-Qāsim ibn Ḥasan al-Shaddād dated 746 H (#7341—Carthage MN)
2 A column sundial by Aḥmad ibn Muḥammad al-Lamṭī dated 747 H (#7342—Tlemcen MSQ)
3 A sundial for Kairouan (#7343—Kairouan MSQ)
4 A sundial from an oasis in Southern Tunisia (#7344—location? MSQ)

5 Ottoman sundials (selected)

Note: Many pieces are featured in Meyer, *Istanbul Sundials* (text in Turkish).

1 An unsigned horizontal sundial (#7351—Diyarbekr MSQ)
2 A polar dial by Ibrāhīm al-Faraḍī al-Kurdī dated 1201 H (#7352—Acre MSQ)
3 A horizontal sundial made during the reign of the Ottoman sultan Mehmet Khān, that is, *ca*. 1475, and renovated by ʿAbdallāh Silaḥdār in 1208 H (#7353—Istanbul TSM)
4 An Ottoman cylindrical dial (#7354—Paris IMA)
5 Various sundials from Istanbul (< Meyer)

6 Indian sundials (selected)

1 A horizontal sundial from Hyderabad (#7381—Hyderabad MSQ)
2 A horizontal sundial from Delhi displaying European influence (#7382—Delhi MSQ)
3 A horizontal sundial based on the principles of folk astronomy from Java, dated 1722 CE (#7383—Gresik)

5 Miscellaneous Eastern instruments

1 Globes (selected early examples)

Note: Nos. 6001-6132 have been assigned to the globes surveyed in Savage-Smith, *Islamicate Celestial Globes*. No globes are included in the Frankfurt catalogue, but here, for the sake of completeness, I list only those that are before *ca*. 1500, as well as a few new ones.

A Early Eastern Islamic globes

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B Early Western Islamic globes

1 Two globes by Ibrāhīm ibn Saʿīd al-Sahlī al-Wazzān
   a) A globe signed by Ibrāhīm and his son Muḥammad and dated 473 or 478 H (#6001 Florence MSS)
   b) Unsigned (#6034—Paris BNF)

C Eastern Islamic globes (12th to 16th century)

1 A globe by Badr ibn ʿAbdallāh Mawlā Badīʿ al-Zamān dated 535 H (#6059—Tehran MIB)
2 A globe by Yūnus ibn al-Ḥusayn al-Asṭurlābī dated 539 H (#6002—Paris IMA)
3 A globe by Qayṣar ibn Abī ʻl-Qāsim ibn Musāfir al-Ashrafī al-Ḥanafī dated 622 H (#6003—Naples MN)
4 A globe by Muḥammad ibn Hilāl al-Munajjim al-Mawṣilī dated 674 H (#6004—London BM)
5 An undated globe by Muḥammad ibn Muʾayyad al-ʿUrḍī (#6005—Dresden SMPS)
6 A globe by Muḥammad ibn Maḥmūd al-Ṭabarī al-Asṭurlābī dated 684 H (#6006+—London NG) with a late copy (#6006—Paris ML)
7 A globe by ʿAbd al-Raḥmān ibn Burhān al-Mawṣilī dated 718 H (#6060—Oxford MHS)
8 Four globes by Jaʿfar ibn ʿUmar ibn Dawlatshāh al-Kirmānī
   a) A globe dated 764 H (#6007—Oxford MHS)
   b) A globe dated 785 H (#6008—Istanbul OBS)
   c) A globe dated 813 H (#6061—Paris IMA)
   d) A globe dated 834 H (#6062—London BM)

New (not recorded by Savage-Smith)

- An unsigned globe datable to the 14th century (#6133—Tartu EAS)
- The horizon base of a celestial sphere by Aḥmad al-Qarīmī dated 1146 H (#6134—Istanbul DM)
- An Ottoman globe (#6135—Istanbul RKM)
- The frame of an Ottoman globe (#6136—Istanbul RKM)

2 Spherical astrolabes

Note: On these see Maddison, "15th-Century Spherical Astrolabe", and Canobbio, "Fragment of a Spherical Astrolabe".

1 A spherical astrolabe by Mūsā dated 885 H (#8001—Oxford MHS)
2 Fragments of a spherical astrolabe from [Tunis] (#8002—Milan PC)

3 Equatoria

1 Fragments of an equatorium by Hibatallāh dated 514 H (#3633 = #8003—formerly Munich PC, now Berlin MIK)

4 Luni-solar gear mechanisms

Note: On this see Hill, "Al-Bīrūnī's Mechanical Calendar".

1 A geared mechanism on an astrolabe by Muḥammad ibn Abī Bakr al-Fārisī (#5 = #8004—Oxford MHS)

5 Compendia

Note: On these see Janin & King, "Ibn al-Shāṭir's Compendium"; Brice & Imber & Lorch, "Equatorial Semicircle"; and Dizer, "Equatorial Semicircle".

1 A *ṣandūq al-yawāqīt*, "jewel-box", by Ibn al-Shāṭir, dated 767 H (#8005—Aleppo IHAS)
2 A plate from a "jewel-box" made by Muḥammad al-Jawharī for al-Wafāʾī in 847 H (#8006—Kandilli OBS)
3 Ottoman examples of al-Wafāʾī's equatorial dial
  a)* Signed by ʿAlī *al-muwaqqit* Abu ʻl-Fatḥ and dated 1161 H (#8010—London NG)
  b) Signed by ʿAlī *al-muwaqqit* Abu ʻl-Fatḥ and dated 1166 H (#8007—Kandilli OBS)
  c) Unsigned (#8008—Kuwait DAI)
  d) Unsigned (#8009—Damascus AM)

6 Qibla indicators (selected)

Note: On these and numerous others, see King, *Mecca-Centred World-Maps*, index on pp. 423-424.

1 The qibla indicator on the compendium of Ibn al-Shāṭir (#8005—Aleppo AM)
2 A ceramic compass bowl by Thābit datable *ca*. 1520 (#8026—Damascus AM)
3* A Safavid disc displaying qibla values (#8028—Graz SLMJ)
3 An Ottoman qibla indicator by Muḥammad ʿIzz al-Ṣabbāgh *ca*. 1800 (#8022—Paris IMA)
4 A Safavid qibla indicator based on a crude geographical scheme (#8023—Oxford MHS)
5 Three undated (late 17th-C) Safavid qibla indicators featuring Mecca-centred world-maps based on a rectazimuthal cartographic projection and a European-type universal inclining sundial
  a) Unsigned (#8024—Kuwait DAI)
  a) Signed by Muḥammad Ḥusayn (#8025—Paris PC)
  a) Signed by Ḥasan Ḥusayn (#8150—Boston PC)

7 Nocturnals
1 A late Maghribi nocturnal (#8091—Oxford MHS)
2 A late Iranian nocturnal (#8092—Oxford MHS)

8 Annular scales
1 Unsigned late Safavid annulus (#8093—Oxford MHS)
2 Annulus signed by ʿAlāʾ al-Dīn (#8094—Chicago AP)

9 Templates for astrolabe construction
1 Unsigned, undated late Safavid template (#8105—Oxford MHS)

X Some fake Eastern astrolabes
On these, see Brieux, "Authenticité des astrolabes"; Gingerich, "Fake Astrolabes", and *idem* & King & Saliba, "The ʿAbd al-Aʾimma Astrolabe Forgeries"; King, "Review of *London Khalili Collection Catalogue*", cols. 257-258; also **X-11** and **XIVf-7**.

INDEXES

Notes: For topics of prime importance, occasional references are given to vol. 1 (parts **I-IX**, but mainly **III**, **IV**, **V**, **VIa-b**, **VIIc** and **VIII**). Also, instruments featured or illustrated in vol. 1, as well as their makers, are indexed here. Lists of manuscripts and titles of books used in **XIIIe** have not been included. Place-names featured in **XVII**-A have not been included. References of the form **N**-p.q:r, **N**-Fm.n, and N-S are to note r in section p.q, Fig. m.n, and Appendix S of part **N**, respectively. In cases where the section is too long to locate easily a particular subject, individual or instrument, a reference may be given to a relevant footnote that will serve to locate the topic in the text.

INDEX OF TOPICS

Notes: The preparation of a complete index featuring all possible references to different parts of the astrolabe proved an impossible task. Those references under "astrolabe" are therefore not to be regarded as exhaustive. Occasionally the order of the sub-entries is thematic rather than strictly alphabetical.

abbreviations → Arabic, Latin

INDEX OF PROPER NAMES

Notes: References to makers of signed instruments from **XVIII** are included here in the form #n / p.q.r, where n is the International Instrument Checklist number and p.q.r is the section number in **XVIII**. This means that numerous Safavid, Moghul and late Maghribi makers are omitted, or if they are included, there are no references to their instruments.

INDEX OF MODERN AUTHORS

Note: The authors listed in the bibliographical notes to **X** have not been included here; however, they are all featured in the main bibliography.

INDEX OF TECHNICAL TERMS

Note: The abbreviations A, P, H and L used here and elsewhere stand for Arabic, Persian, Hebrew and Latin, respectively.

INDEX OF MANUSCRIPTS

INDEX OF INSTRUMENTS CITED IN THE TEXT

Note: Lists of instruments used in various individual studies are appended to **XI**, **XIIa**, **XIIb**, **XV** and **XVI**. The reader should also consult the Index of instruments listed in **XVIII**, which follows. Identifications of the instruments are usually to be found *ad loc*. The makers of signed instruments are listed together with the # numbers in the Index of persons. References to **XVI**-A indicate that the latitudes featured on the instruments have been compared with those on contemporaneous instruments.

INDEX OF INSTRUMENTS FEATURED IN **XVIII**

Notes: This list should be used in conjunction with the preceding Index of instruments featured in the text. For abbreviations of locations see **XVIII**. The makers of signed instruments are listed together with the # numbers in the Index of persons.

ADDENDA AND CORRIGENDA TO IN SYNCHRONY WITH THE HEAVENS ... ..., VOL. 1: THE CALL OF THE MUEZZIN

ADDENDA

II-13.0: Since there is so little material available on astronomical timekeeping in al-Andalus, we should mention a new survey of this in Samsó, "Social History of Science in al-Andalus", pp. 522-524, and also *idem*, "Medición del tiempo en al-Andalus *ca*. 1000". These studies should be consulted in conjunction with *idem*, "Astronomical Observations in the Maghrib".

IV: This study dealt mainly with the times of the *ẓuhr*, *ʿaṣr* and *ḍuḥā* prayers. I was unaware that there was an early debate about the time of the *maghrib*: see Wasserstrom, "The Delay of the Maghrib: A Study in Comparative Polemics" (1984), which was kindly brought to my attention by Petra Schmidl (Frankfurt). On the topic of the Aramaic origin of the word *ṣalāt* (see pp. 597-598) my friend Professor Paul Kunitzsch kindly alerted me to the article listed as Spitaler, "Ṣalāt in der Koranischen Orthographie".

VIIc: The maker of the second Mecca-centred world-map (**B**) signed himself "Muḥammad Ḥusayn". In my book *World-Maps for Finding the Direction and Distance to Mecca* (pp. 255-274), I went to some trouble to try to identify this individual. One strong contender was Muḥammad Ḥusayn ibn Muḥammad Bāqir (al-)Yazdī, known from textual sources as an instrument maker. His father, Muḥammad Bāqir Yazdī, was the leading mathematician of Safavid Iran.

Only in January, 2004, did I learn, from my friend Jacques van Damme, that an astrolabe, signed by Muḥammad Ḥusayn ibn Muḥammad Bāqir al-Yazdī and dated 1058 H [= 1647/48], with diameter 12 cm, had been auctioned at Sotheby's of London on 21.09.2000 (lot 27): see **Fig. 1**. The instrument was described in the auction catalogue in a rather amateurish fashion: the distinctive rete, unique amongst Safavid astrolabes, was described as "restrained"; the stars were listed backwards; the gazetteer on the mater was mentioned only in passing (a single entry, carefully chosen, would have been useful); a shadow scale for base 23 (!!!) did not evoke comment; the fact that there was no plate for Isfahan or Yazd (!) was ignored; and the maker is labelled "probably a shi'ite" (!!). Worse, there was no illustration of the back or the signature or another partially erased inscription on the back. There was no indication of any resemblance of the signature to that of my Muḥammad Ḥusayn, which is illustrated in my book and reproduced again in detail here (**Fig. 2**), although all of the information presented in the auction catalogue on Muḥammad Ḥusayn ibn Muḥammad Bāqir al-Yazdī was taken from that book, and the possible identity of the two individuals was mentioned. Sotheby's has informed me that no such photos were made, and that the instrument is no longer accessible. An illustration of the signature would have solved the
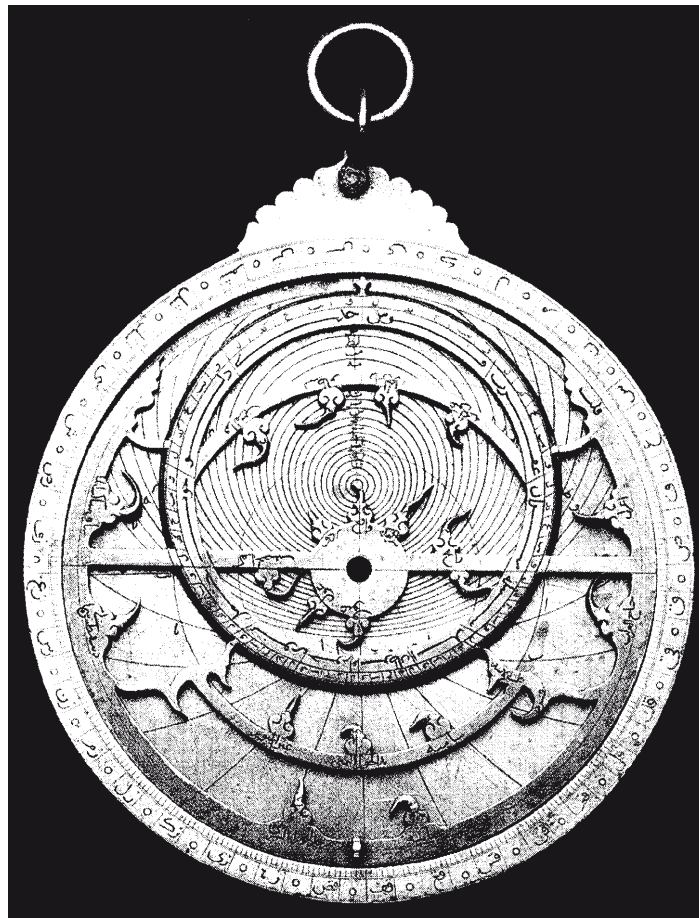
Fig. 1: The front of the newly-rediscovered astrolabe of Muḥammad Ḥusayn ibn Muḥammad Bāqir al-Yazdī (#4304), which *could have* provided the answer to the question whether or not this individual is identical to the maker of the world-map whose signature is shown in **Fig. 2**. Alas, no photos of the back of this astrolabe are available. [Photo courtesy of Sotheby's of London.]
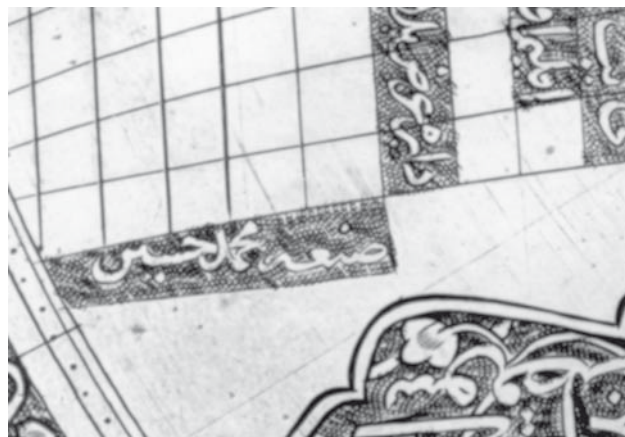
Fig. 2: The signature of Muḥammad Ḥusayn on the second world-map (#8025). [Photo by the author, courtesy of the owner.]

question whether my Muḥammad Ḥusayn was the same person as the man who made this astrolabe. All of this is, as the Arab cartoonists say, *bidūn taʿlīq*.

IX: Perhaps the remarkable tables for timekeeping by the stars that I tentatively associated with **Qandahar** in 2001 were actually compiled for **Basra**, a possibility that I considered at the time but dismissed (see n. 18 on p. 894). The connection with Qandahar (or Kirman, which I also mentioned) rather than Basra was further strengthened by the fact that some of them were compiled by a man named al-Balkhī, from Balkh in C. Asia, although this in itself would not exclude al-ʿIrāq. Medieval Basra would not otherwise have been known for any astronomical activity.* As noted, I had considered Kirman, whose latitude was generally taken as 30°,** but no astronomical activity is known there until much later, when the al-Kirmānī family of astrolabists was active (see **XIVd-2**).

Actually, given the events of 2003-04, it hardly matters whether my tables were for Qandahar or for Basra or for Kirman. The same tables would serve any of these cities, and my message is equally valid for them all. They will not serve any locality in Syria (an embargo was announced in May, 2004), but there are many other tables I could use for the next time. At the Medieval Iraq Study Day in the British Museum on May 15, 2004, I suggested that we meet again soon for a Medieval Syria Study Day. Or maybe Iran will be next?

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* The assertion in Kennedy & Kennedy, *Islamic Geographical Coordinates*, pp. xxxv and 473, that in the anonymous set of geographical tables preserved in MS Utrecht Or. 23 (14th century), the longitudes are reckoned from the meridian of Basra, is incorrect. In Kennedy, "Islamic Mathematical Geography", p. 189, it is withdrawn because no location is mentioned for the base meridian. In fact, no "base meridian" is intended other than the local meridian for which the solar, lunar and planetary tables are calculated. The table displays latitudes and *longitude differences*, the latter being zero for Abhar and Shamakha as well as Basra. Since the *"Utrecht" zīj* is related to two *zīj*es from N. W. Iran, the *Shāmil* and *Athīrī Zīj*es, the former anonymous and the latter by Athīr al-Dīn *al-Abharī*, the meridian in question is most probably intended for Abhar. Furthermore, the latitude given for Basra in this source is given as 31;0°, whereas the tables I investigated were for latitudes 30;25° and *ca*. 30;0°, both attested in other early sources for Qandahar.

** Kennedy & Kennedy, *Islamic Geographical Coordinates*, pp. 187-188. The latitude 30;25° is not attested for Kirman. Its accurate latitude is 30°18′.

CORRIGENDA

A list of errata was included in Vol. 1 after it had been printed and before it was released. In the case of several of those noted below, the errors were actually corrected, the corrections checked, and then—lo and behold!—they reappeared. The original errata are repeated here, new ones being asterisked. A plus sign indicates that the error is significant.

++ The title of the volume should read:

IN SYNCHRONY WITH THE HEAVENS
Studies in Astronomical Timekeeping and Instrumentation in Medieval Islamic Civilization
VOLUME ONE
THE CALL OF THE MUEZZIN
(STUDIES I-IX)

To put it another way, the words "(STUDIES I-IX)" belong not to the main title of both volumes, but rather to vol. 1.

* p. vii: The information in vol. 1 on the contents of vol. 2 is no longer valid
p. xiv, para. 2, l. 14: for "book: they do" read "book. They do"
+ p. xv, para. 2, l. 4: for "is it is" read "is it"
+ p. xvi, para. 1, l. 9: the sentence beginning "Islamic science ... " should not be indented
+ p. xvi, para. 2, l. 9: for "al-Khwārīzm" read "al-Khwārizmī". [Here the font let us down and the long vowels came out mangled. Last-minute instructions over the phone went something like: "Make the 'a' long and then make the 'i' long", and this is what actually happened. Compare n. 11 to VIIc on p. 835.]
+ p. xix, Part XIIIe: for "as in" read "as "An Astrolabe from 14th-Century Christian Spain with Inscriptions in Latin, Hebrew and Arabic—A Unique Testimonial to an Intercultural Encounter" in"
* ++ p. xix: The information in vol. 1 on the previous publication of various parts of vol. 2 is upgraded in vol. 2
p. xx, para. 1, end of l. 2, insert as second sentence: "Some additional sources on instruments will be included in Vol. 2."
p. xxi, *etc*., header: for "ABBREVIATIONSS" read "ABBREVIATIONS"
p. xxv, King, "Aspekte": for "1993. [A new version" read "1993. A new version"
p. xxxvi, l. 2: for "to appear in *AS* • (200•)." read "*AS* 61 (2004), pp. 1-13."
p. xxxvi, l. 10: for "GAS" read "*GAS*"
p. xlii, "Michel, *Scientific Instruments* ... ": for "London: •••, 1967." read "London: Barrie & Rockliff, 1967."

* p. xliii, under Nasr: for "“nsan" read "İnsan".
p. xlvi, Poulle, "Instruments astronomiques", ll. 1-3: for "Moyen Age," Museum ... ... 1st edn." read "Moyen Age", 1st edn."
p. l, l. 3 of entry for Schellerup: for "repr.s" read "repr."
p. lvii, Zinner, *Verzeichnis*: title should be in italics

p. 65, caption to Fig. 2.3.5, l. 3: for "fols." read "fol."
p. 67, l. 5: for "(**No. 10.1**)" read "(**10.1**)"
p. 97, caption, l. 2: for "degrees the sign" read "degrees of the sign"
p. 168: only the left hand side of each image should have been featured here
* pp. 173-174: the curious rectangular box appearing twice amongst the formulae was supposed to be a ± sign upside down
p. 215, para. 1, l. 4: for "65r, 5700" read "65r, and 5700"
* p. 229, last line of 2.9: for z' read Z
* p. 378, last line, read: the functions are denoted by f_ϕ and g_ϕ, where ϕ is the local latitude.
p. 407, caption to Fig. 11.7, l. 2: for "fols. 87v-88r" read "fol. 87v"
+ p. 534, para. 2, l. 3: for "Islamio" read "Islamic"
p. 547, l. 3: read "pilgrim sets"
* + p. 549, n. 15: read "al-Khaṭīb al-Baghdādī"
* + p. 571, section 5.2, for al-Qāsim ibn Ḥasan ibn al-Shaddād read Abu ʻl-Qāsim ibn Ḥasan al-Shaddād
* p. 576, caption to Fig. 5.5, penultimate line: read "copyist's"
* p. 581, n. 3: read "century"
* p. 585, n. 11: read "Professor"
* p. 589, n. 14: for "Mabaʿat" read "Maṭbaʿat"
* p. 590, n. 16: for "Mabaʿat" read "Maṭbaʿat"
* p. 591, n. 23: for "Mabaʿat" read "Maṭbaʿat"
* p. 593, n. 30: for "Makta-bat" read "Maktabat"
p. 598, n. 10, for "Schrieke.," read "Schrieke,"
p. 603, n. 27, l. 2: for "Testa-ment" read "Testament"
p. 605: header should read "CONCLUDING REMARKS"
* p. 607, *ad* 5.3: read "*al-ẓāhira*"
* p. 665, n. 13, l. 2: for "treaties" read "treatises"
+ p. 697, caption to Figs. 9.2a-c, l. 3 from bottom: insert " } " before full stop
p. 788, n. 9, l. 1: for "al-Amīrujya" read "al-Amīriyya"
p. 834, l. 2: read "central"
+ p. 861: a colour image such as appeared on the jacket of the book was not available for the text of the book: see the note to p. 872
* p. 894, 8 l. from bottom: for **X-4.8** read **XIIIa-9**
+ p. 872: a colour image was used here in anticipation of the availability of a colour image for the illustration on p. 861 (see above), but the latter became available only in time to be used for the jacket

* p. 904: for Ibn Manīūr read Ibn Manẓūr
* p. 904: for al-Qāsim ibn al-Ḥasan read Abu ʻl-Qāsim ibn Ḥasan. I suggest keeping the appellation "Ibn al-Shaddād".
p. 910, col. 2: for "*taʿdīl-i al-ẓuhr*" read "*taʿdīl-i ẓuhr*"
p. 922, Cambridge Browne O.1: for "al-abarī" read "al-Ṭabarī"
p. 923, Escorial ár. 941: for "al-Quṭrubī" read "al-Qurṭubī"
p. 926, Topkapı AIII 3515: for "Kātib" read "ibn Kātib Sinān"
p. 929, Princeton Garrett Hitti 1016: for "al-Ṭawāsh" read "al-Ṭawāshī"
* + p. 885, l. 4: for "turkey" read "Turkey" (!).
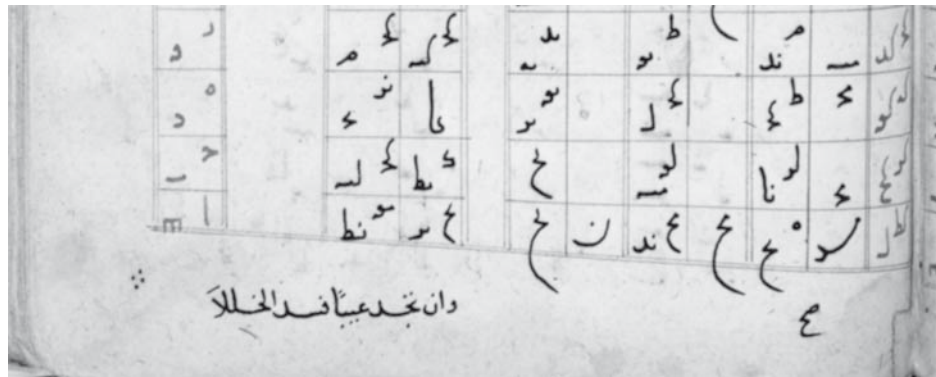
Fig. 3: A request by a medieval copyist penned at the end of dozens of pages of astronomical tables. It translates more or less as: "If you find a mistake, (please) fix it." [From MS Dublin CB 3673 of the Cairo corpus of tables for timekeeping; courtesy of the Chester Beatty Library.]

The reader who finds other errors in these two volumes is requested to follow the injunction of a medieval Egyptian copyist illustrated in **Fig. 3**.